VIBRATION EFFECTS ON PILOT TRACKING PERFORMANCE USING A RIGID CONTROL STICK

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THESIS

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USING
A RIGID CONTROL STICK

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Vibration Effects on Pilot Tracking Performance Using A Rigid Control Stick

by

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ABSTRACT

A simulator facility was built to study the effects of vibration on pilot tracking performance using a rigid control stick. Tests were conducted at frequencies from 5 to 50 hertz and accelerations up to 1.5 g's. Two vibration environments were studied: control stick only vibration and whole body vibration.

Twenty-two different frequency/g-level combinations were tested. The order of the runs was varied for each subject in an attempt to cancel out consistent learning effects. In general, performance scores for whole body vibration were lower than those for control stick only vibration although g-levels were less. All subjects experienced greater discomfort on the whole body vibration tests. All subjects showed a noticeable drop in performance on some runs in the 20-25 Hz frequency range. Additional study into vibration effects is warranted and comparisons should be made between effects using rigid and moveable control systems.

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I. INTRODUCTION

Within the past few years increased research has been done into the feasibility of electronic control systems for aircraft control (fly-by-wire). These control systems are being proposed as both primary control for new aircraft and as backup systems for present aircraft.

These investigations of fly-by-wire have led to the consideration of rigid force sticks in place of the conventional moveable sticks. In an attempt to determine aircraft handling qualities based on pilot opinions using different types of sticks, a simulator evaluation of pilot performance and acceptance of an aircraft rigid cockpit control system was made at the Naval Postgraduate School in 1970 (Ref. 1). This investigation determined that a rigid control system was superior in performance and pilot opinion to a moveable system. An important limitation on this study, however, was the lack of aircraft vibration effects.

Reference 2 details results of a study in which a moveable stick and a force stick were evaluated under vibration conditions. It was found that the moveable stick gave superior performance at all frequencies and intensities of vibration tested. However, these tests were limited to frequencies of 2 and 4 hertz and only up to 0.5 g's. The report stated that the predominant whole aircraft response of large transport aircraft is near 2 Hz but that smaller military aircraft

exhibit responses which have peaks at higher frequencies (3-5, 11, 20 Hz). It also stated that military aircraft are more subject to air induced vibrations due to their extended operating envelopes and thus may experience greater g levels than those studied.

It becomes apparent then that further study is needed on the effects of vibration on pilot performance using the rigid stick, particularly in relation to the higher frequencies and g levels experienced in military aircraft. The objective of the present study was to attempt to measure the effects of vibration using the rigid stick at frequencies from 5 to 50 Hz and at various g levels up to 1.5 g's. Acceleration amplitude is a function of both frequency and displacement amplitude; however, since displacements are in general small and the acceleration amplitude is felt to have greater physiological significance, it was decided to make tests on preselected acceleration levels rather than displacement levels.

Since the man/machine interface is an important factor in vibrational effects on individual performance, two distinct vibration environments were studied. In the first, only the control stick itself was vibrated with resultant transfer to the operator through his hand and arm. In the second, the operator's entire body was vibrated through the platform on which he was seated.

II. SIMULATOR FACILITY

The simulator facility enabled a test subject to perform a two-dimensional tracking task while subject to vibration. It also provided a scoring system for quantitative measurement of his performance. The facility consisted of three main areas. The first was the control stick itself which was mounted on a shaker table with an X-Y cathode ray tube (CRT) oscilloscope for pilot's display. The second area was the shaker table control panel (Fig. 1) and the third was the operator's panel (Fig. 2) which contained an analog computer for simulating aircraft dynamics, a tape recorder to present a repeatable test signal, and various components and controls to perform the scoring function.

A. RIGID CONTROL STICK

The control stick consisted of four strain gages mounted on an aluminum flexure with an epoxy handgrip. The stick and its associated wiring were mounted on a quarter-inch aluminum control box which also served as the pilot's armrest. The two strain gages in each direction were connected to Wheatstone bridges contained in a balancing box at the operator's panel. An adjustable potentiometer permitted balancing each bridge to zero output under no-load conditions. More detailed information on the stick and the bridge circuit is contained in Ref. 1.

The stick was attached to the shaker table in two different setups. In Setup One, the control stick box was mounted directly on the shaker armature so that vibration was transmitted to the stick itself and through it to the pilot's hand and arm. Figure 3 shows the stick mounted on the shaker and Figure 4 shows the stick and the CRT display under operating conditions.

In Setup Two, a platform was mounted on the shaker armature and the control stick box was attached to the side of the platform (Fig. 5). The pilot was seated on the platform and his whole body was vibrated (Fig. 6).

B. SHAKER SYSTEM

The shaker system consisted of a Calidyne shaker and an LTV servo control system. Frequency was adjustable from 5 Hz to 5 kHz with acceleration levels up to 100 g's. At low frequencies, however, the g level attainable was limited by maximum allowable displacement.

C. TAPE INPUT

In order to generate the two-dimensional tracking task a random signal consisting of four low frequency (.01-.16Hz) sine waves was recorded on two channels of an Ampex tape recorder for approximately a 40-minute period. Figure 7 shows a representative sample of the random signal in the lateral and longitudinal directions. The test signal was played back and passed through a summing amplifier to the CRT. In order to eliminate high frequency "noise" from the

signal a one-microfarad capacitor was patched across the output of the tape recorder.

D. ANALOG COMPUTER

A Pace TR-10 analog computer was used to simulate aircraft dynamics and also perform summing and comparator functions. The computer circuits for aircraft lateral and longitudinal dynamic response are shown in Figures 8 and 9.

The lateral circuit is an approximation of aileron input to a stable aircraft, i.e., a steady aileron force is required to maintain a constant bank angle. The output of the circuit represents bank angle, ϕ, although it appears on the oscilloscope as a displacement and is more analagous to yaw angle.

The longitudinal circuit approximates the short period response of an aircraft at 0.9 Mach. The output is the pitch angle, θ, and since in the short period approximation airspeed and altitude are assumed constant, the θ change will remain in the circuit until removed.

In initial test runs with equal amplification on the lateral and longitudinal circuits several subjects complained of a lack of directional sensitivity as compared to the longitudinal control. Although a portion of this difference may be due to the different dynamics of the two circuits, it was felt that most of it was merely the nature of the human wrist to be able to apply more force longitudinally than

laterally. This was corrected by amplifying the simulated aileron deflection by an additional factor of ten over that of the elevator deflection.

E. SCORING SYSTEM

During scoring runs the test signal from the tape recorder was sent through a summing amplifier and presented on the oscilloscope. The subject being tested was to attempt to cancel out this signal by proper movement of the control stick and thus keep the CRT display pip centered. In order to measure the effectiveness of the subject's response, a scoring circuit was set up to record the period when the pip was within a predetermined distance of the center of the oscilloscope. This circuit is shown in Figure 10.

The sum of the required control deflection, as determined by the tape input, and the actual control deflection from the analog dynamic circuit results in error signals in both longitudinal and lateral directions which are presented on the oscilloscope. The error signals are then amplified by a factor of five and passed through inverters. Both the signals and their negatives are fed through diodes to the comparator IN-1 terminal. The increase in signal magnitude was required to activate the diodes, which require 0.5 volts to pass current. The inverters are necessary so that both plus and minus signals will trigger the comparator. An input bias voltage is patched to the IN-2 terminal of the comparator. This bias voltage may be varied to adjust the size of the CRT display scoring area.

The comparator relay connects the output of a 10 Hz oscillator to an electronic counter so that when both the longitudinal and lateral error signals are less than the input bias voltage the electronic counter is energized and records the time that the pip is within the scoring area to the nearest tenth of a second.

A function switch on the TR-10 control panel permits starting and stopping of the counting sequence as desired for timed runs.

F. DISPLAY PRESENTATION

An X-Y cathode ray tube oscilloscope was used as the pilot's display. Both scales were set at 0.5 volts/inch so that full deflection occurred at $\pm$ 2.0 volts longitudinally and $\pm$ 2.5 volts laterally. The scoring area was set as a one inch square centered at the middle of the scope, i.e., $\pm$ 0.5 inch. This required a comparator bias voltage of -1.25 volts to IN-2.

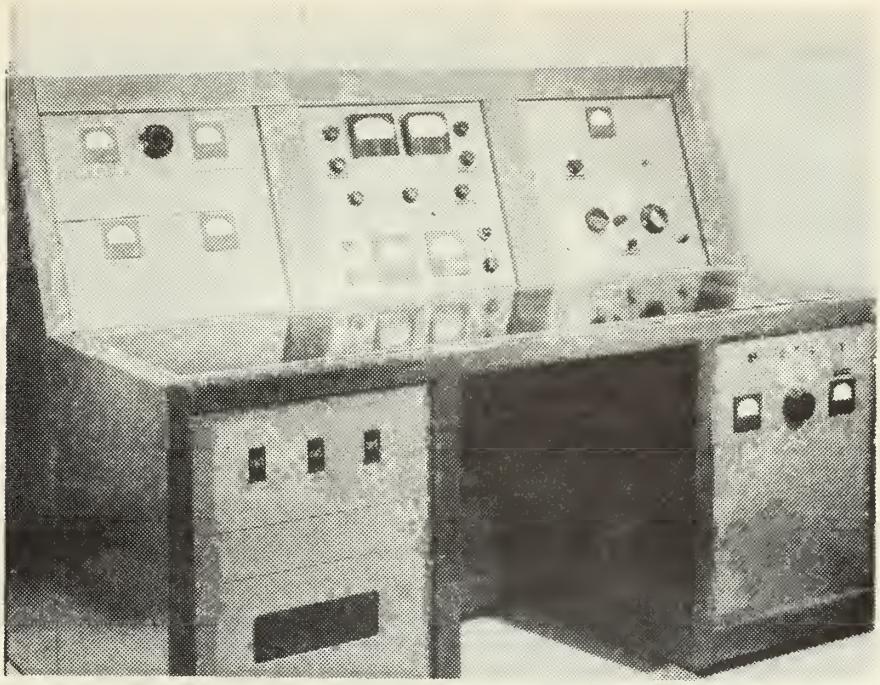


Figure 1. Shaker Table Control Panel

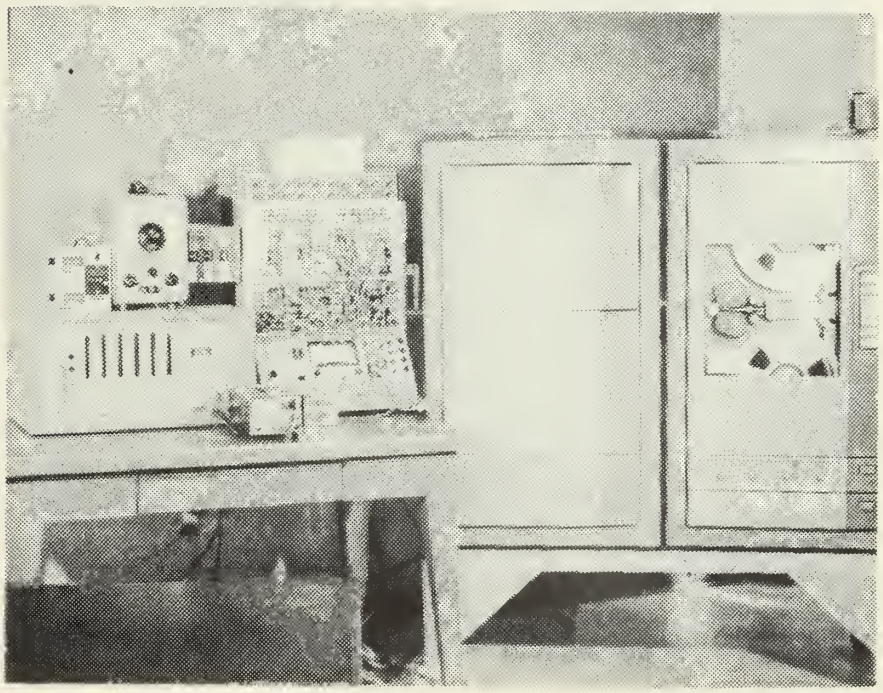


Figure 2. Operator's Panel

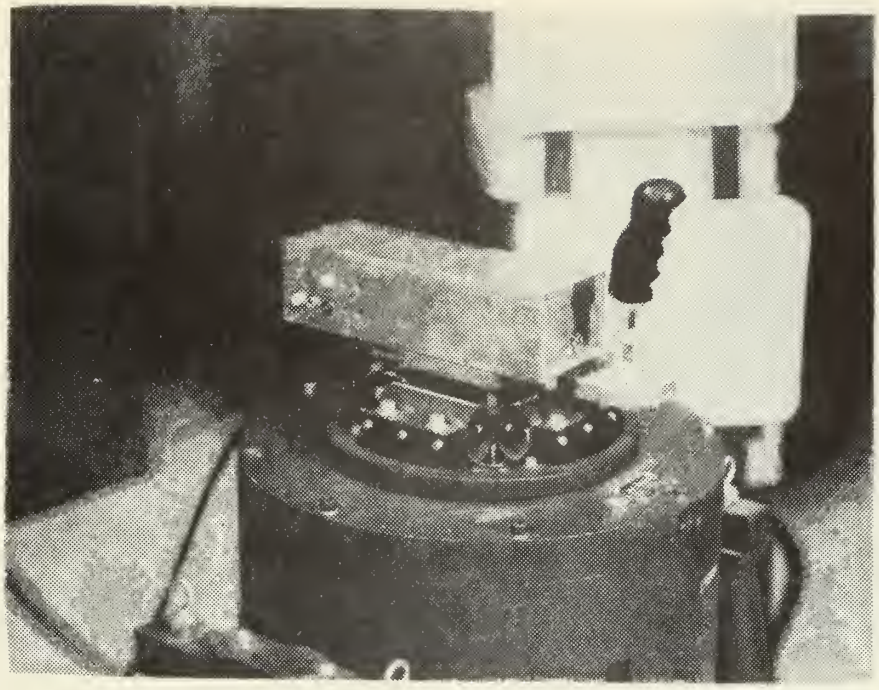


Figure 3. Stick Mounting-No. 1.

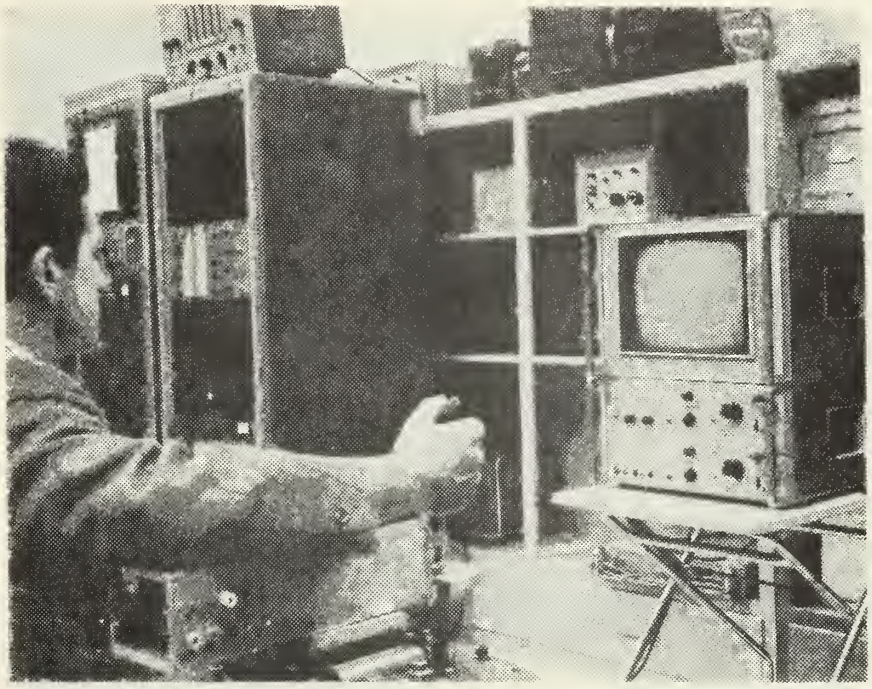


Figure 4. Stick Operation-No. 1.

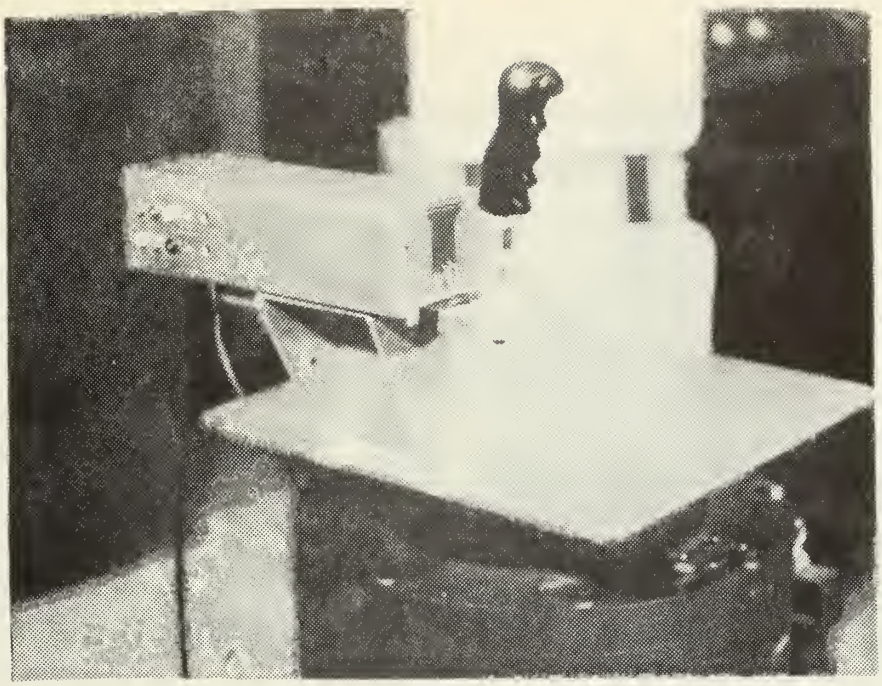


Figure 5. Stick Mounting-No. 2.

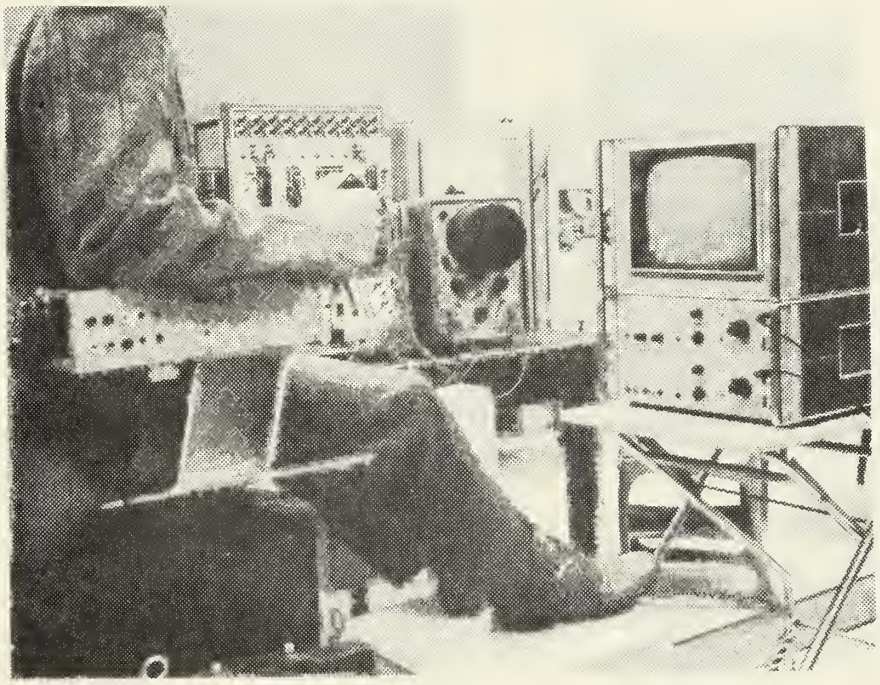


Figure 6. Stick Operation-No. 2.

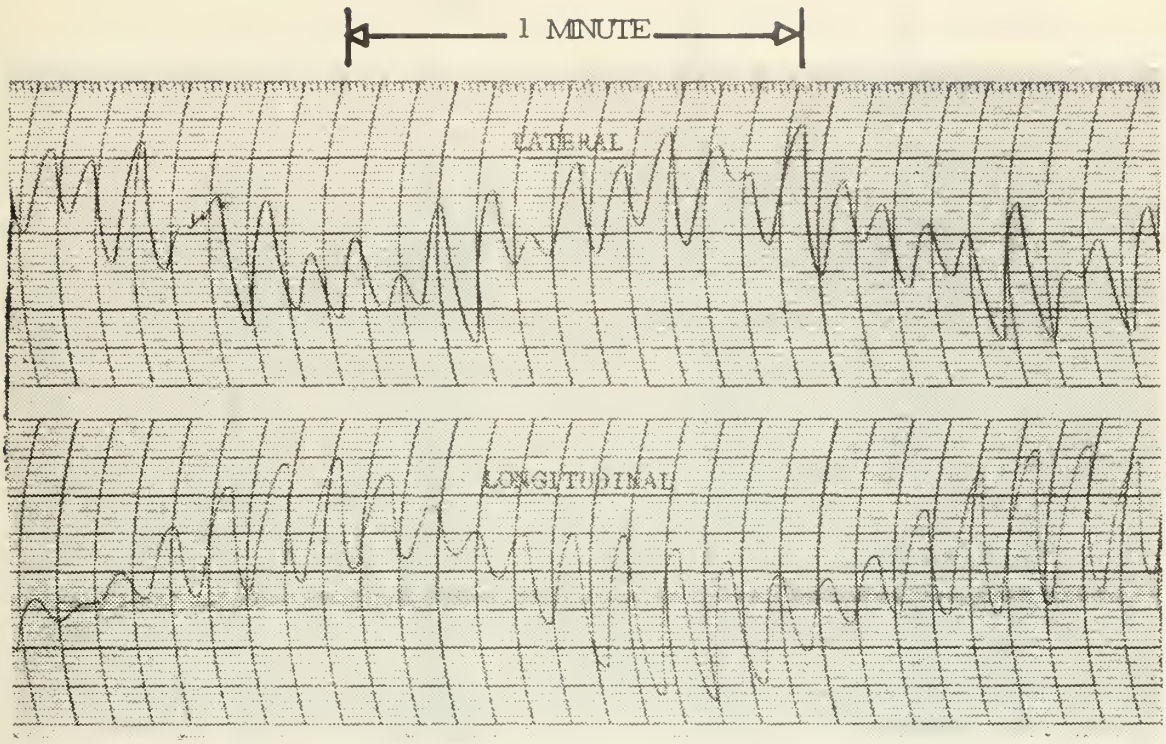


FIGURE 7. TAPE OUTPUT

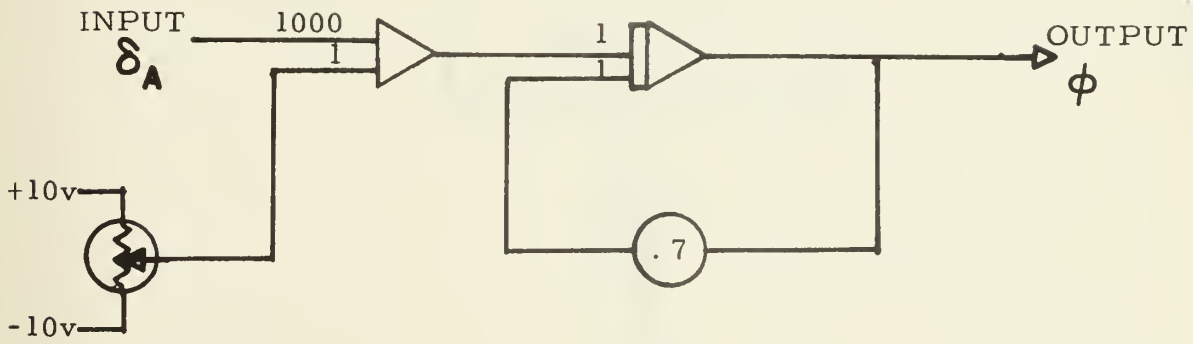


FIGURE 8. LATERAL DYNAMICS

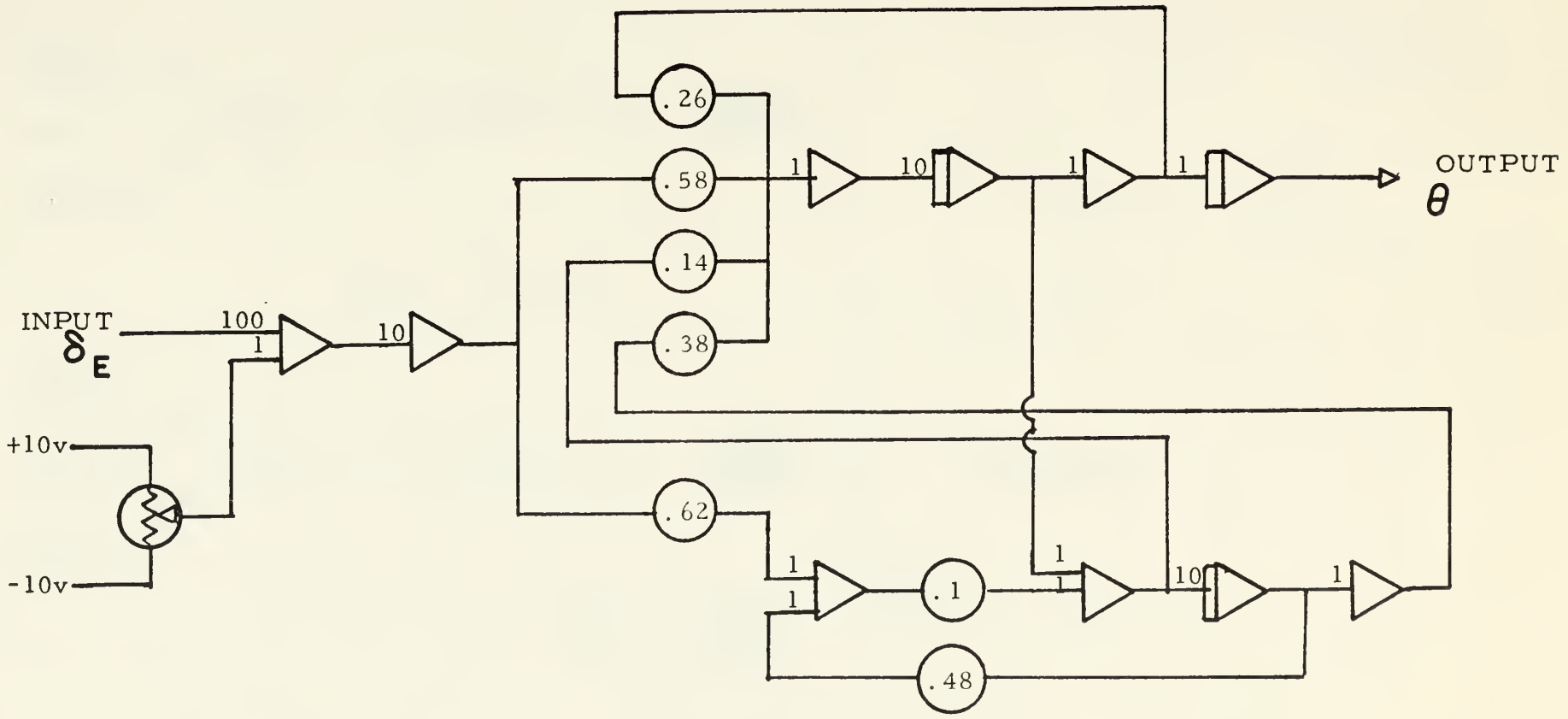


FIGURE 9.

LONGITUDINAL DYNAMICS

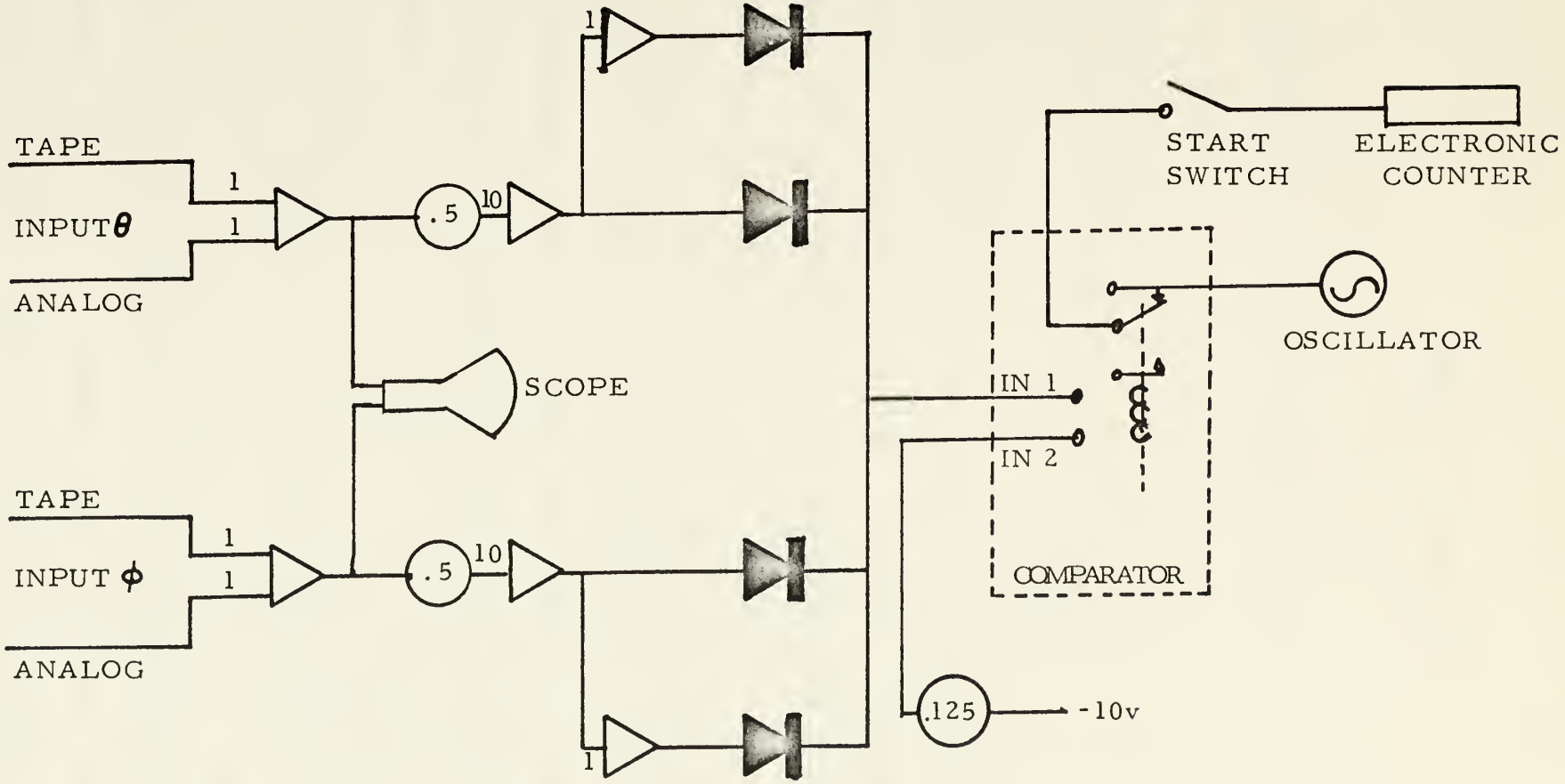


FIGURE 10.

SCORING CIRCUIT

III. TESTING PROCEDURES

The testing procedure consisted of two separate runs on each of five different subjects. The first was with the stick itself vibrated (Setup One) and the second was with the subject's entire body vibrated (Setup Two) as described in the previous section. The two runs were conducted on each subject about two months apart. Each run consisted of two static tests and 22 vibration tests at different frequency and g-level combinations as shown in Table I. At g-levels one and two, tests were made at 5 Hz intervals up to 50 Hz. Preliminary results showed the major effects to be at frequencies below 30 Hz so g-level three was run at 3 Hz intervals from 15 to 30 Hz.

At the start of the run the subject was briefed on simulator operation, scoring procedures and test sequence. He was shown a demonstration on the oscilloscope of the random test signal from the tape recorder and was then given a short period on the stick to become familiar with its operation and sensitivity. This familiarization was conducted with no input signal and no vibration. The subject was then given a one-minute practice period with a tape input but without scoring. Then followed a one-minute scoring run under static conditions. The 22 scoring runs of one minute each were then completed. In an attempt to cancel out any learning effects the 22 runs were conducted in a different random order for each subject. The tape recorder was

recycled after the eleventh run of each set. At the conclusion of the 22 vibration tests an additional static test was made. The entire sequence of familiarization, test runs, and static runs lasted approximately one hour for each subject.

No restriction was placed on the subject's movement or rest period between individual tests. During the runs of Setup One (stick vibration only) all subjects remained seated throughout the entire sequence and runs were made continuously with the only break being the time taken to change the shaker table controls. During the Setup Two runs (whole body vibration) several subjects got up to move around between runs and two requested rests up to 3 minutes after some runs.

Subjective comments on the test were not solicited at any time but during the Setup Two runs several subjects volunteered comments on the uncomfortable feeling of a particular frequency and g-level combination.

TABLE I

FREQUENCY AND G-LEVEL COMBINATIONS

G-level	Frequency-Hz											
	5	10	15	18	20	21	24	25	27	30	40	50
1	X	X	X		X			X		X	X	X
2		X	X		X			X		X	X	X
3			X	X		X	X		X	X	X	

Setup One --------- G-level One=0.5g rms.

G-level Two=1.0g rms.

G-level Three=1.5g rms.

Setup Two -------- G-level One=0.25g rms.

G-level Two=0.40g rms.

G-level Three=0.60g rms.

IV. SUBJECT DATA

Subject	Age	Flight Time	Operational Aircraft
1	29	1800	P-3
2	28	1600	P-2
3	30	1800	H-3
4	34	4400	S-2
5	30	*	*

* Non-pilot

V. TEST RESULTS

For each run the score achieved was the total time, to the nearest tenth of a second, that the subject was able to keep the pip within the scoring area. For each subject the score of the static tests at the beginning and end of each run were averaged in order to obtain a "normal" score without vibration. All other scores of the run were then divided by this value to give normalized scores for comparison purposes. Raw and normalized scores for all subjects are shown in Appendix B. Tests on which the subject made a particular comment on the discomfort involved are marked with asterisks. These all occurred on Setup Two.

The average scores for all subjects and all g-levels versus frequency are shown in Figure 11 for both Setups One and Two. Although there are some large deviations with frequency, it can be seen that in general the scores for Setup Two were lower than those of Setup One even though the corresponding g-levels were less. Figures 12 and 13 show the results for all subjects at g-level one. The main point of note on these figures is that deviations from the average are less on Setup Two. The results for other g-levels are similar and appear in Appendix C.

A selected group of individual scores is shown on Figures 14, 15, and 16. These figures represent three different subjects at

three different g-levels but all show a noticeable dip in the range 20-25 Hz on both Setups One and Two. These figures are representative of the entire group. In fact, of the fifteen graphs of this type, (5 subjects, 3 g-levels), ten show this distinct dip at 20-25 Hz on one or both of the runs. These graphs appear in Appendix D.

The 22 test runs were conducted in a different random order for each subject in an attempt to cancel out consistent learning effects. A typical learning curve, a plot of score versus run number, is shown in Figure 17.

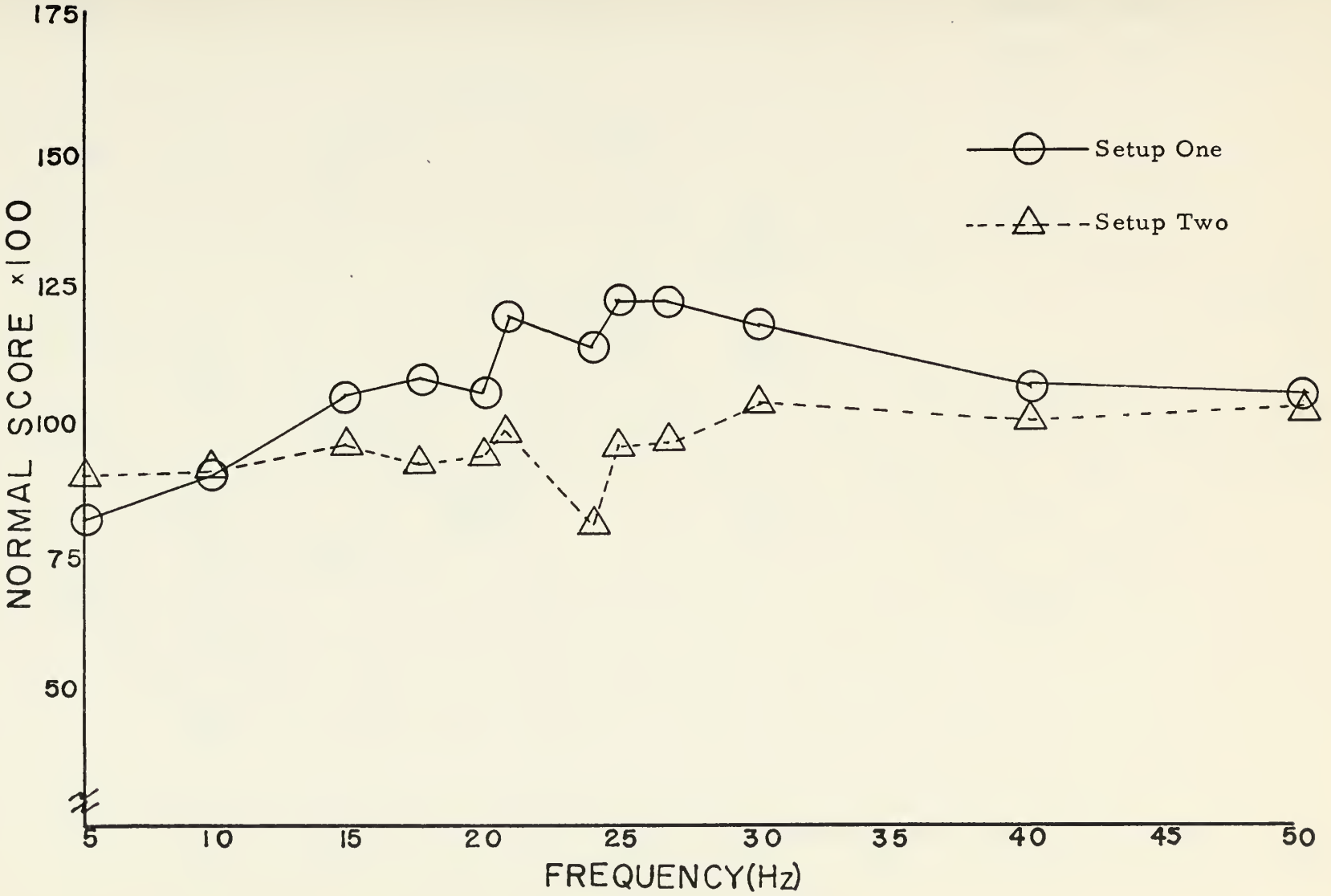


FIGURE 11. AVERAGE SCORES

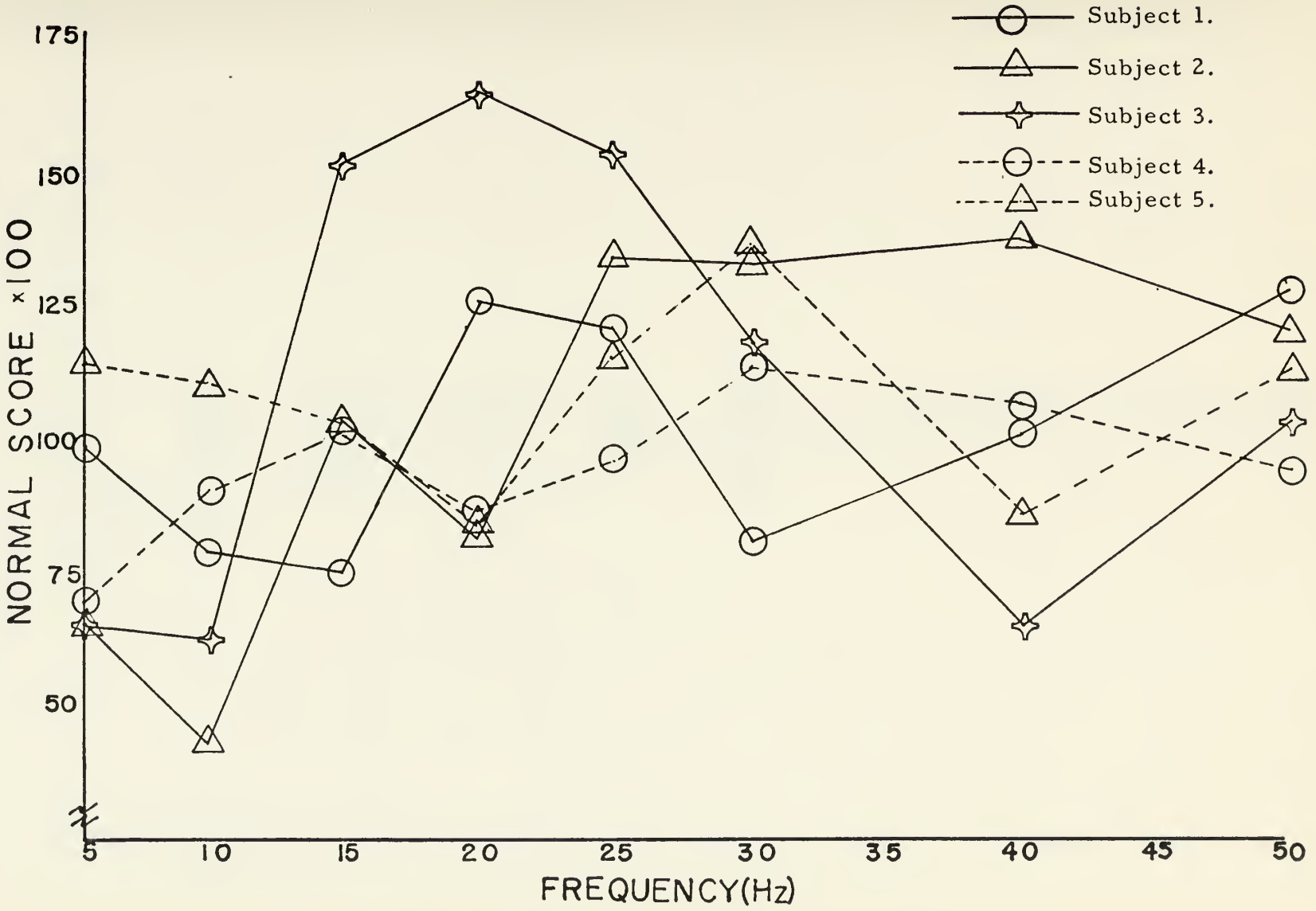


FIGURE 12. SCORES--SETUP ONE--G-LEVEL ONE

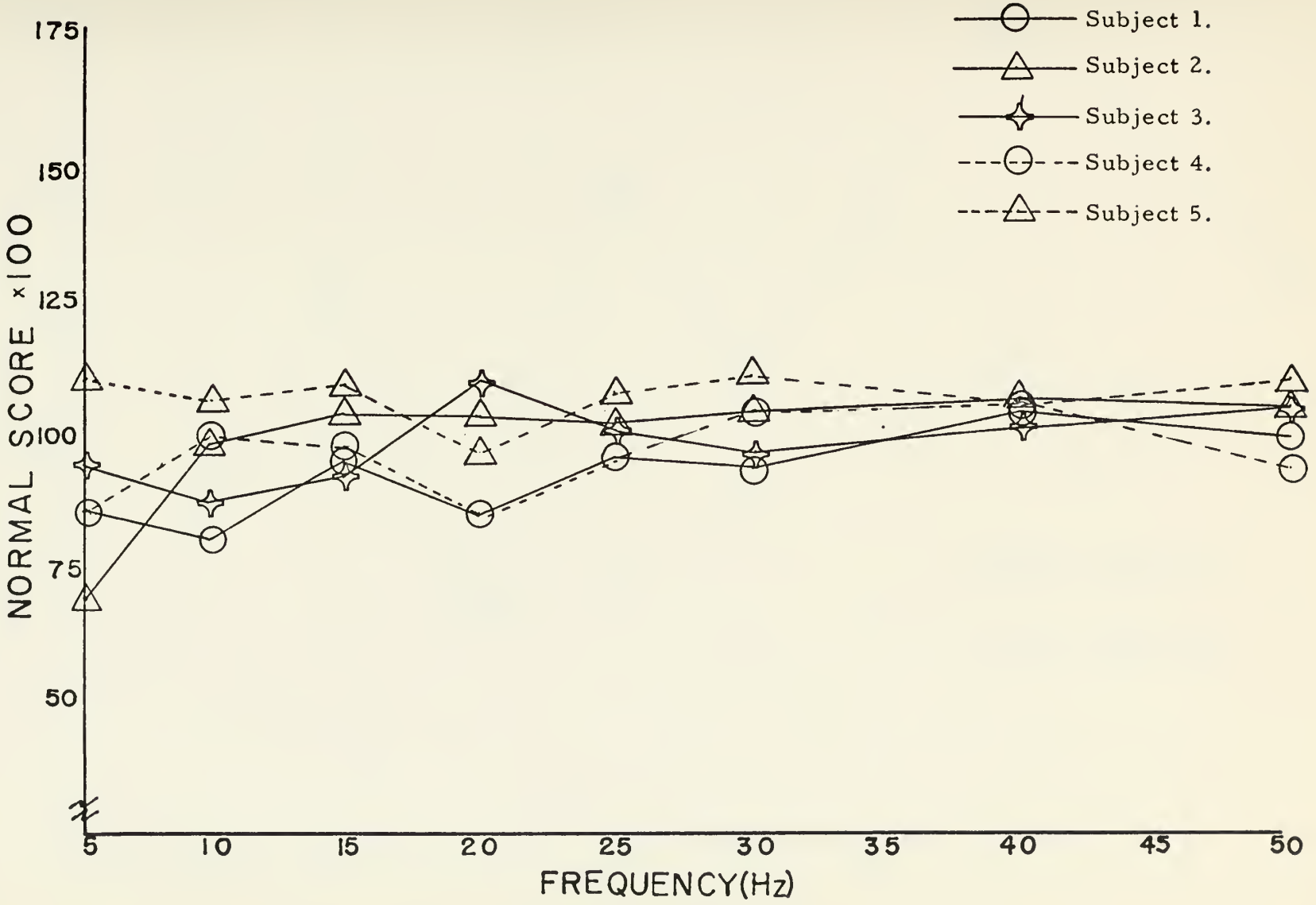


FIGURE 13. SCORES--SETUP TWO--G-LEVEL ONE

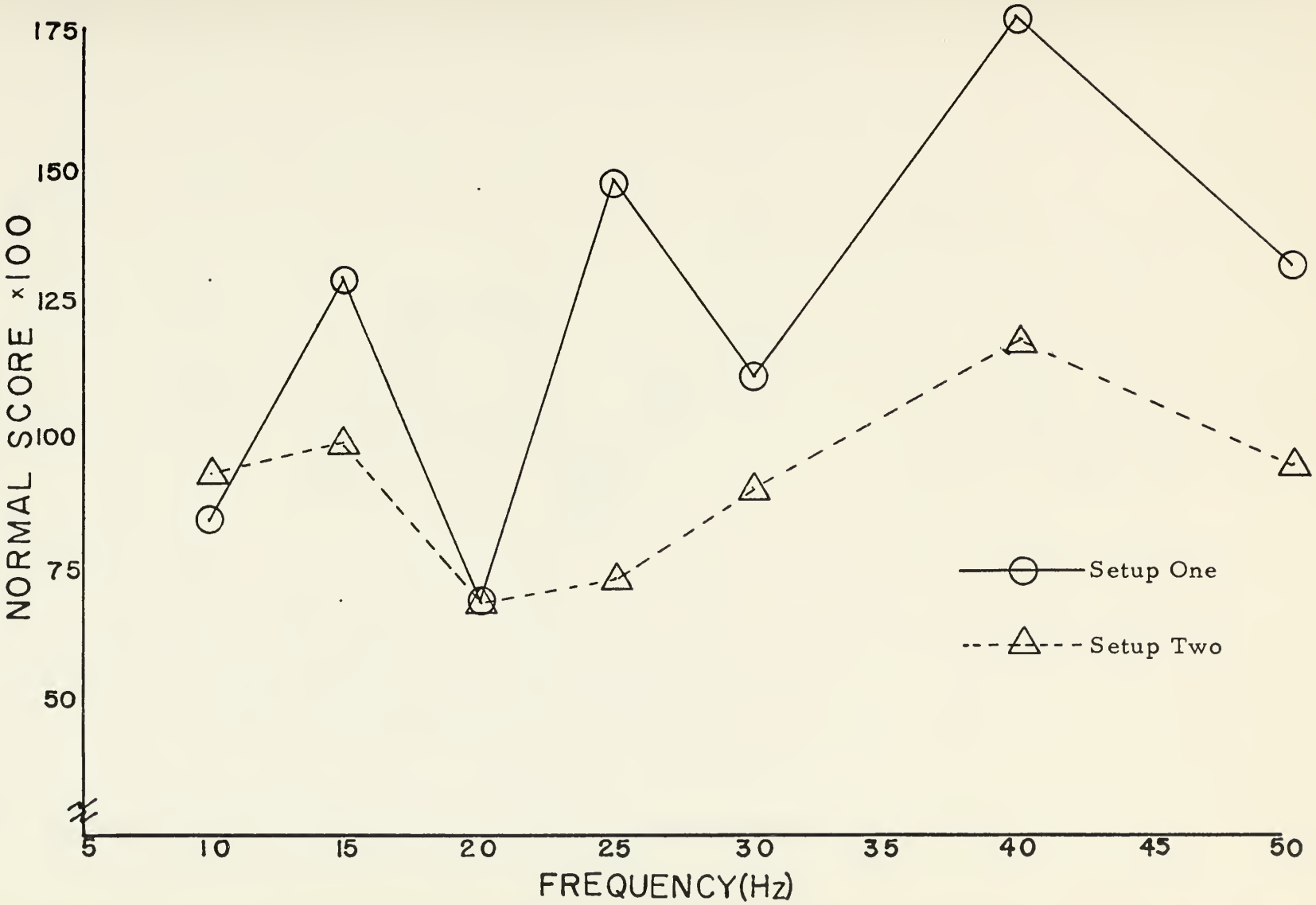


FIGURE 14. SCORES--SUBJECT 3-- G-LEVEL TWO

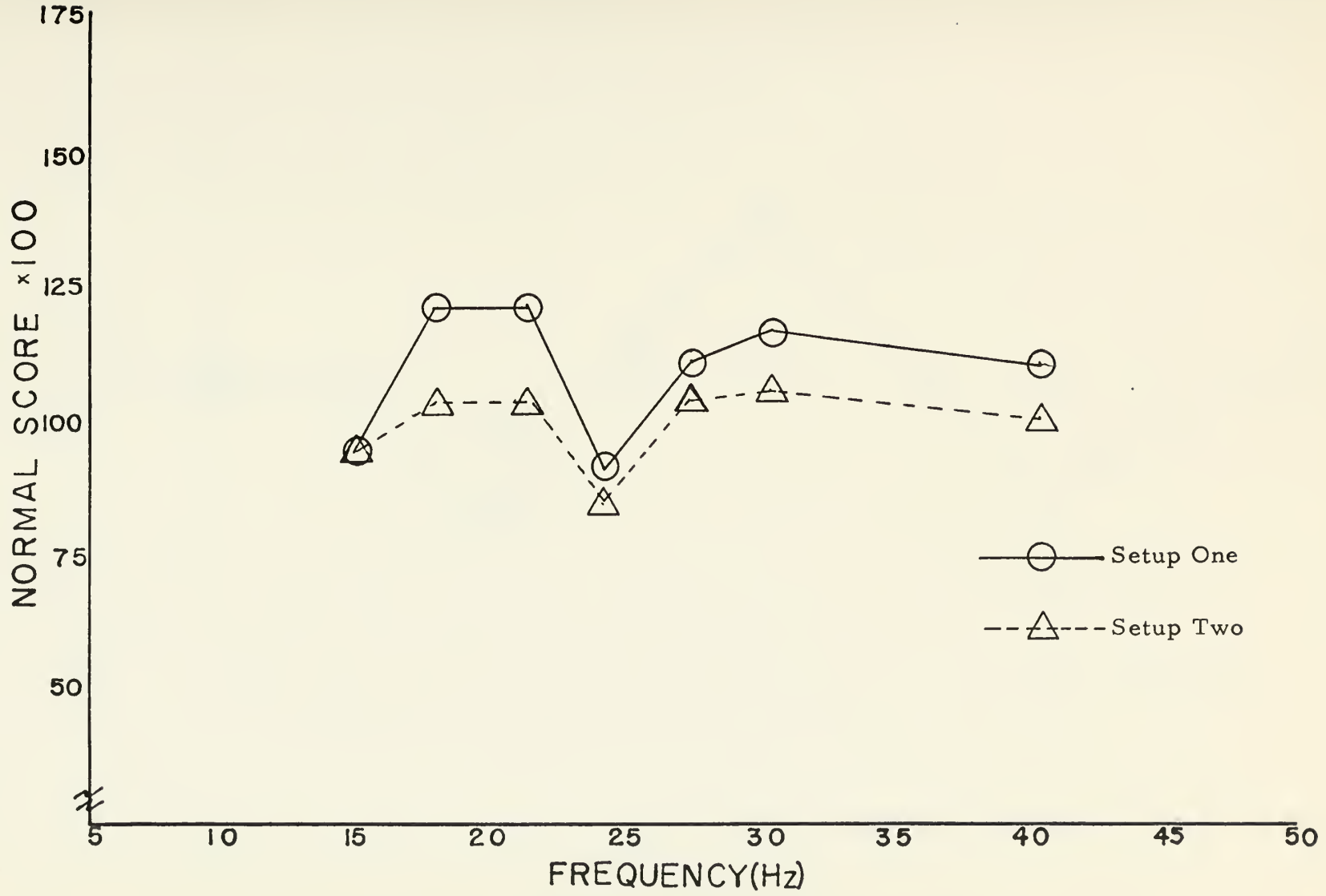


FIGURE 15. SCORES--SUBJECT 4--G-LEVEL THREE

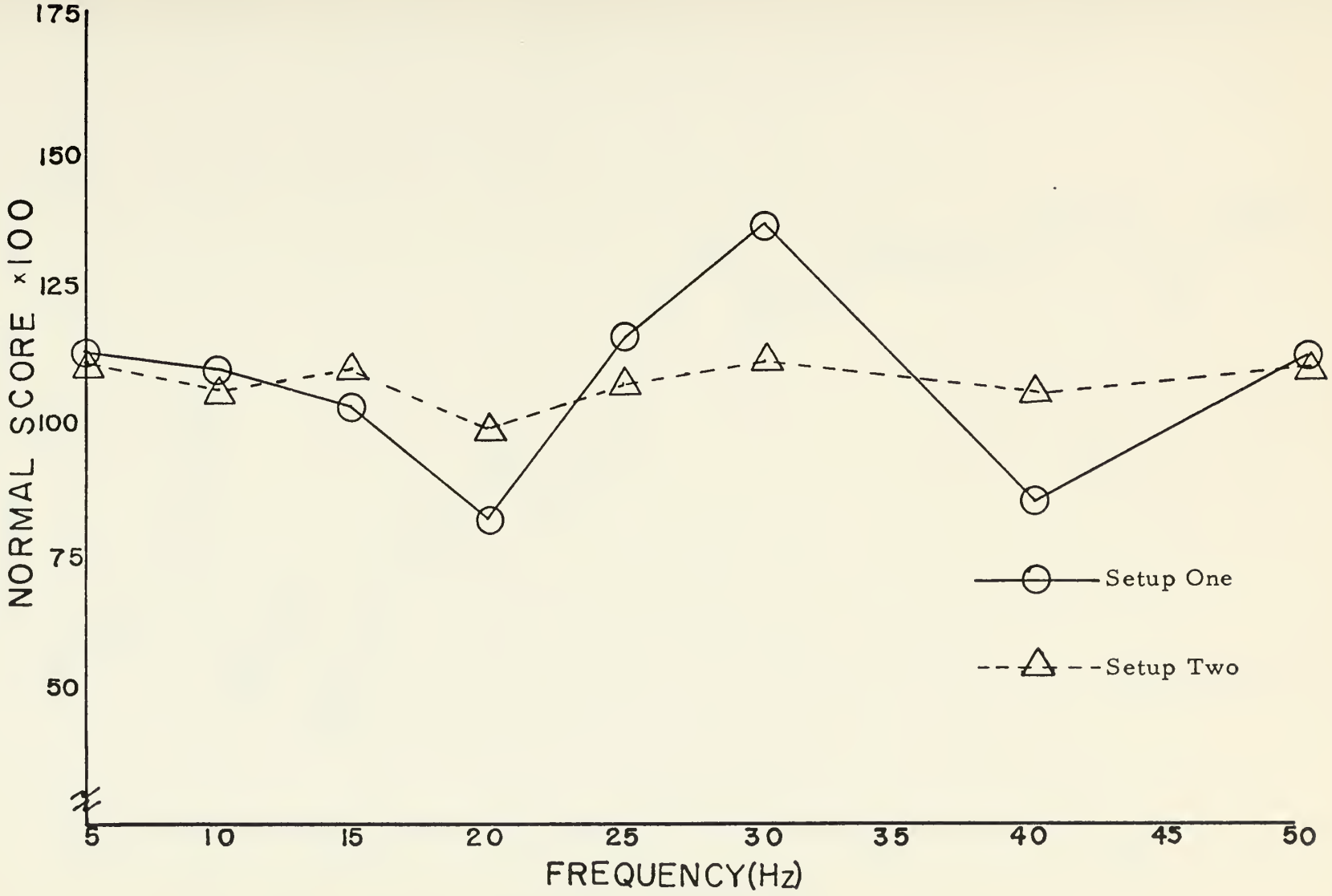


FIGURE 16. SCORES--SUBJECT 5--G-LEVEL ONE

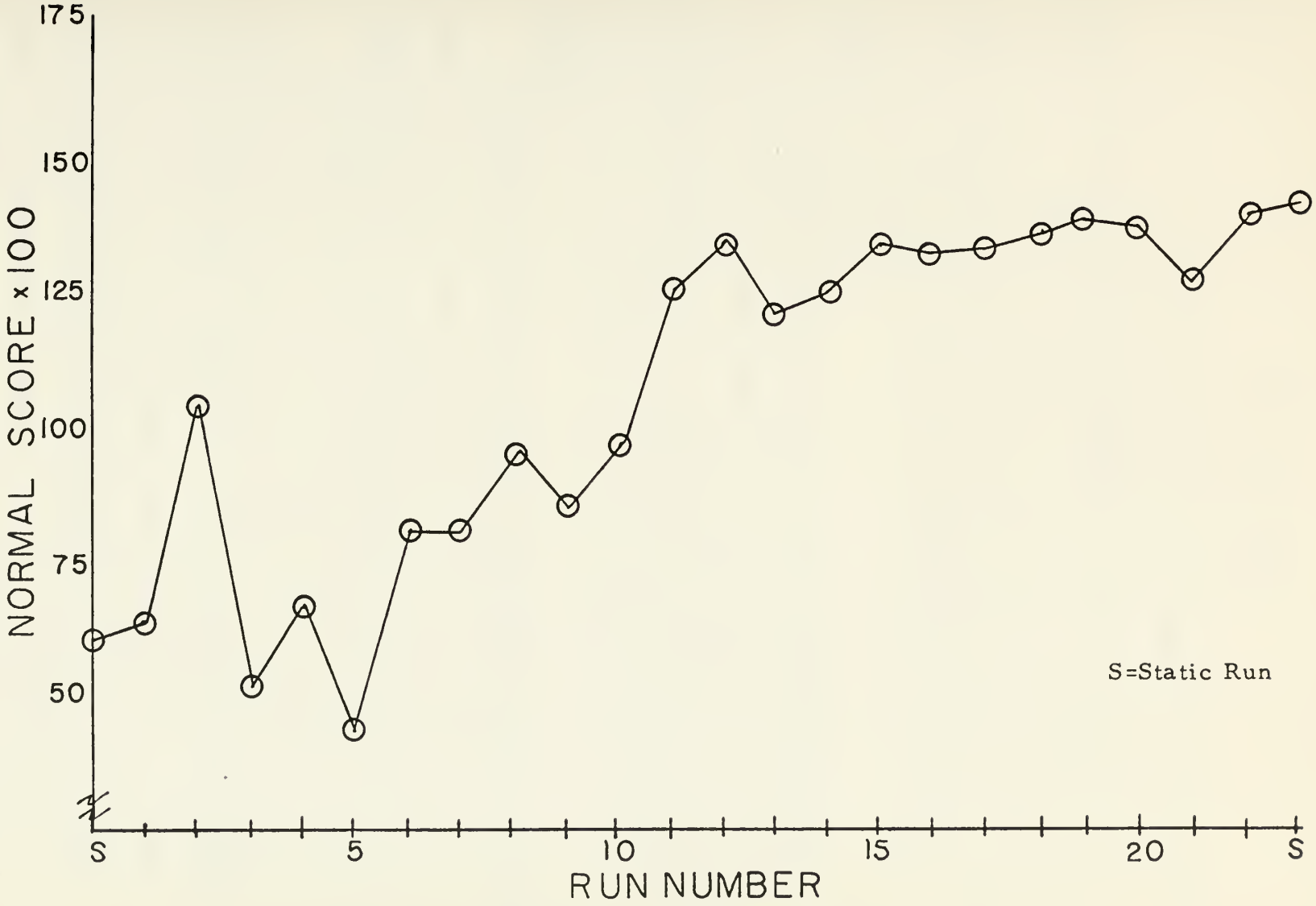


FIGURE 17. LEARNING CURVE

VI. DISCUSSION

Scores on Setup Two were overall lower than those of Setup One. This occurred despite the fact that the g-levels on Setup Two were at least 50 per cent less than those of Setup One. A possible reason was that in Setup One the hand and arm tend to damp out vibration from the rest of the body while in Setup Two with whole body vibration the damping is much less.

On an individual basis, scores on Setup One exhibited larger deviations from average than those of Setup Two. This shows that for isolated vibration, i.e., hand/arm only, individual body size and build may be a contributing factor to the amount of body damping involved.

Of the five test subjects only two, (#2 and #4), showed a noticeable performance degradation at five Hz. This was the lowest frequency tested and is close to the 4½ Hz predicted for body resonance in Ref. 3.

All subjects showed a marked drop in performance on some runs in the 20-25 Hz frequency range. Subject five showed this drop on all runs at 20 and 21 Hz. Reference 4 discusses some of the possible reasons for decreased performance at these frequencies although little research has been done to measure the effect. Near 20 Hz there is a large relative movement between head and shoulder although movement of the head itself is small. There is also a visual

acuity problem caused by eyeball resonance within the orbital cavity at a frequency near 20 Hz.

All subjects experienced greater discomfort on Setup Two compared to Setup One. Although comments were not solicited all subjects expressed a feeling of discomfort after certain tests on this run. Ten such comments were received while none were received on Setup One. Of these ten comments, seven occurred at frequencies of 20-25 Hz and eight occurred along with a corresponding drop in performance, (Appendix D).

All subjects displayed some learning effects during the tests. Scores in general appeared to improve with succeeding runs, independent of frequency and g-level. Hopefully the different random order of scoring runs prevented this from influencing the overall results.

VII. CONCLUSIONS

One conclusion that can be drawn from the previous results is that vibration effects are both difficult to measure and difficult to interpret. During measurement, the effects of the vibration itself must be distinguished from the effects of learning and fatigue. Learning effects are hopefully cancelled out by using different orders of test for each subject. In an attempt to minimize fatigue, individual tests were kept short. Scores attained at various time intervals, from 30 seconds to 3 minutes, were compared for some subjects and appeared to be fairly consistent. Based on this, a test run length of one minute was chosen as a compromise between scoring accuracy and subject fatigue.

Interpretation of vibration results must consider several factors including the effects of frequency, g-level, and individual subject response. Averages can sometimes be used to give an overview of the situation but care must be taken that this does not obscure pertinent results from individual tests. For example, Figure 12, although more cluttered than Figure 11, presents a better picture of the large differences among vibration effects on individual subjects.

The objectives of this study were to measure vibration effects at higher frequencies and g-levels than previous studies and to compare two different types of vibration environments, i.e., whole-body

vibration and control-stick-only vibration. Very little data were recorded at frequencies less than 10 Hz - only one g-level on each setup. This low frequency range has been extensively investigated in the past. Reference 4 is a summary of some research in this area.

In the range of frequencies above 10 Hz, the most noticeable effects on performance occurred at 20-25 Hz. All subjects demonstrated degraded performance in this range on at least one run. This appeared at all g-levels and may have been caused by an increase in head movement and a decrease in visual acuity due to eyeball resonance.

The two vibration setups tested provided information on the effects of the vibration environment. The different setups seemed to have a larger effect on pilot comfort than on pilot performance. All the "discomfort" comments received during the project occurred on Setup Two although performance on these runs was in general comparable to that of Setup One at the same vibration level. This points out that on the short test runs involved here, pilot comfort or discomfort is not a true indicator of performance. Reference 3 also concluded that vibration can have a large effect on flight crew performance while being within acceptable comfort limits. For long time exposure, i.e., extended flights in a vibration environment, pilot comfort assumes greater importance since discomfort itself can induce fatigue which causes a further degradation of performance below that due to the vibration alone. For this reason it is important that pilots' seats be well damped at any critical frequencies expected to be encountered for sustained periods of vibration.

Vibration does have a definite effect on pilot tracking performance using the rigid control stick. Some possible contributing factors are involuntary movement of the pilot's hand and arm, visual problems at certain frequencies, and discomfort-induced fatigue after extended exposure. Although this study has shown vibration effects to be present, further research is necessary to accurately quantify the extent of their influence and suggest possible remedies. These future studies might consider the following factors. Longer test runs can be made to determine the long-time effects of vibration on comfort and fatigue. An increased number of subjects should be tested, both to provide a broader data base and to provide criteria for identifying vibration sensitive persons. Different amounts of pilot and seat damping can be used in order to produce an environment which will reduce vibration effects at critical frequencies. Finally, an attempt should be made to provide data on vibration effects using conventional moveable controls so that an accurate comparison of rigid and moveable systems may be made.

APPENDIX A

LIST OF EQUIPMENT

1. Shaker - Calidyne Model 219 Shaker
2. Shaker Control - Ling Electronics Division, LTV Inc.

   Model S-11 Servo System
3. Tape Recorder - Ampex 8 Channel
4. Analog Computer - Electronic Associates Inc.

   Pace TR-10 Model 7350
5. Oscillator - Hewlett Packard Model 202A

   Low Frequency Function Generator
6. Counter - Berkeley Division, Beckman Co.

   Universal Eput and Timer
7. Oscilloscope - Hewlett-Packard Model 143A
8. Power Supply - Power Mate BP-34C

   Regulated Power Supply

APPENDIX B

SCORING DATA

		SUBJECT									
		1		2		3		4		5	
FREQ	G-LEVEL	ORDER	SCORE	ORDER	SCORE	ORDER	SCORE	ORDER	SCORE	ORDER	SCORE
0	-	-	34.5	-	25.6	-	10.2	-	39.8	-	35.5
5	1	8	39.9	1	27.1	12	19.2	2	33.5	22	48.0
10	1	7	31.9	5	18.3	3	17.9	14	44.0	11	46.4
15	1	1	30.6	2	43.4	20	43.8	6	48.8	15	43.5
20	1	14	50.3	6	34.1	22	47.3	1	42.0	3	35.0
25	1	18	48.7	12	56.3	18	44.1	4	46.0	8	48.4
30	1	6	32.3	17	55.7	7	34.0	13	54.6	18	57.2
40	1	2	41.4	18	52.4	2	18.9	12	51.6	6	36.4
50	1	21	51.8	13	51.0	6	29.6	5	45.6	14	47.7
10	2	10	40.5	7	33.9	9	24.4	16	50.7	21	58.8
15	2	11	46.9	3	22.0	14	37.3	7	43.8	10	50.9
20	2	9	43.7	9	36.5	1	20.2	22	59.3	4	46.1
25	2	13	44.5	11	52.5	11	42.1	15	56.6	19	52.2
30	2	4	44.1	19	58.6	8	32.2	19	59.0	7	38.9
40	2	3	33.0	16	54.9	21	50.9	10	41.4	13	54.8
50	2	20	32.3	21	54.0	17	37.9	11	46.5	2	24.5
15	3	12	37.8	4	29.8	19	36.5	3	46.3	16	56.0
18	3	16	36.8	8	40.9	4	25.8	21	58.1	20	58.2
21	3	19	49.1	10	42.2	15	48.3	17	58.3	5	39.3
24	3	17	34.6	14	52.1	10	40.3	8	43.3	17	55.1
27	3	22	45.5	20	57.6	13	40.8	9	53.9	12	48.3
30	3	5	37.1	22	59.1	16	38.7	18	56.3	9	56.2
40	3	15	44.1	15	55.7	5	18.9	20	54.8	1	33.9
0	0	-	47.4	-	59.4	-	48.0	-	57.2	-	49.6

RAW SCORES - SETUP ONE

		SUBJECT									
		1		2		3		4		5	
FREQ	G-LEVEL	ORDER	SCORE	ORDER	SCORE	ORDER	SCORE	ORDER	SCORE	ORDER	SCORE
0	-	-	49.0	-	51.7	-	33.7	-	53.2	-	49.5
5	1	8	46.1	1	38.4	12	41.7	2	48.3	22	58.4
10	1	7	42.6	5	53.8	3	38.2	14	56.0	11	56.2
15	1	1	50.7	2	57.2	20	40.6	6	54.4	15	58.2
20	1	14	44.8	6	56.8	22	47.5	1	47.6	3	52.5
25	1	18	51.2	12	55.8	18	44.1	4	54.3	8	57.6
30	1	6	50.5	17	57.8	7	42.2	13	58.5	18	58.9
40	1	2	55.3	18	58.4	2	44.4	12	59.2	6	55.8
50	1	21	53.5	13	58.4	6	46.9	5	53.0	14	59.0
10	2	10	44.4	7	41.5	9	41.1	16	48.4	21	55.1
15	2	11	44.8	3	54.8	14	43.9	7	57.0	10	56.6
20	2	9	52.6	9	55.9	1	30.3	22	57.3	4	47.1
25	2	13	39.7	11	52.6	11	32.3	15	58.3	19	58.7
30	2	4	46.5	19	57.6	8	38.6	19	58.6	7	59.2
40	2	3	51.2	16	59.4	21	51.5	10	51.2	13	58.5
50	2	20	51.9	21	58.4	17	42.2	11	58.1	2	55.8
15	3	12	40.0	4	54.3	19	38.8	3	53.6	16	59.1
18	3	16	44.6	8	52.6	4	31.2	21	58.2	20	59.7
21	3	19	46.7	10	48.7	15	45.2	17	57.3	5	56.0
24	3	17	41.5	14	49.7	10	16.6	8	47.5	17	58.4
27	3	22	53.3	20	56.4	13	31.1	9	57.2	12	58.3
30	3	5	53.3	22	59.2	16	48.5	18	59.2	9	58.3
40	3	15	53.7	15	54.1	5	27.2	20	57.1	1	54.1
0	-	-	58.1	-	57.9	-	54.6	-	59.4	-	58.2

RAW SCORES - SETUP TWO

		SUBJECT									
		1		2		3		4		5	
		SETUP		SETUP		SETUP		SETUP		SETUP	
FREQ	G-LEVEL	1	2	1	2	1	2	1	2	1	2
0	-	84	91	60	94	35	76	82	94	84	92
5	1	98	86*	64	70	66	95	69	86	113	109
10	1	78	79	43	98	62	87	91	99	109	105
15	1	75	95	102	104	150	92	100	97	102	108
20	1	123	84	80	103	162	108	86	85	82	98*
25	1	119	96	132	102	151	100	95	96	114	107
30	1	79	94	131	104	117	96	112	104	135	110
40	1	101	103	135	107	65	101	106	105	86	104
50	1	127	100	120	107	102	106	94	94	112	110
10	2	99	83	80	76	84	93	104	86	138	102
15	2	115	84	52	100	128	99	90	101	120	105
20	2	107	98	86	102	69	69*	122	102	108	88*
25	2	109	74*	124	96	145	73	116	104	123	109
30	2	108	87	138	105	111	88	121	104	92	110
40	2	81	96	129	108	175	117	85	91	130	109
50	2	79	97	127	107	130	96	96	103	57	104
15	3	92	75	69	99	125	88	95	95*	132	110
18	3	90	83	96	95	89	71*	120	103	137	111
21	3	120	87	99	89*	166	103	120	102	92	104
24	3	85	77*	123	91	138	38*	89	84	130	109
27	3	111	99	136	103	140	71	111	102	114	108
30	3	91	99	138	108	133	110	116	105	132	108
40	3	108	100	131	99	65	62	112	101	80	101
0	-	116	109	140	106	165	124	118	106	116	108

* "Uncomfortable"

NORMAL SCORES x100

APPENDIX C

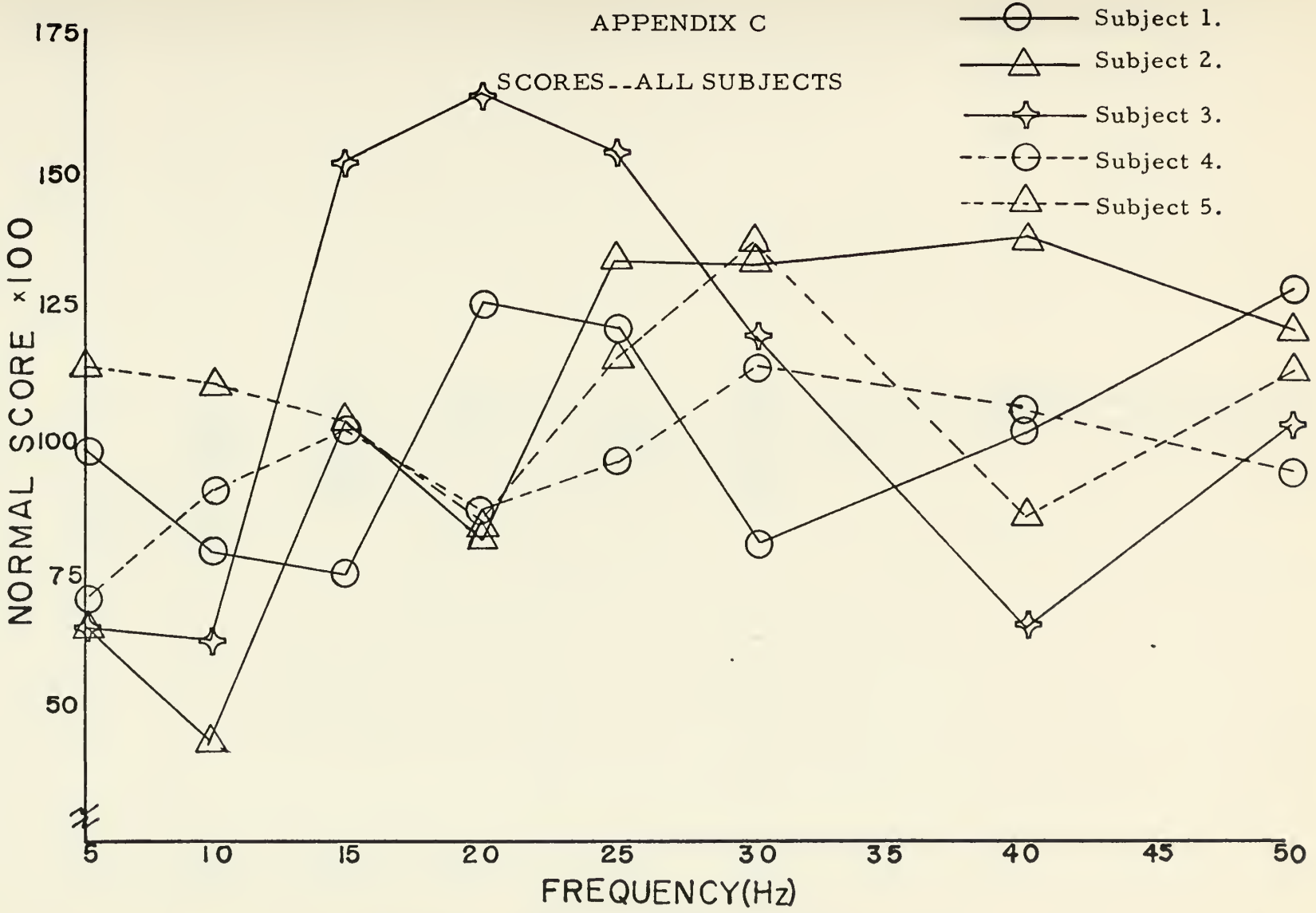


FIGURE C-1. SETUP ONE - G-LEVEL ONE

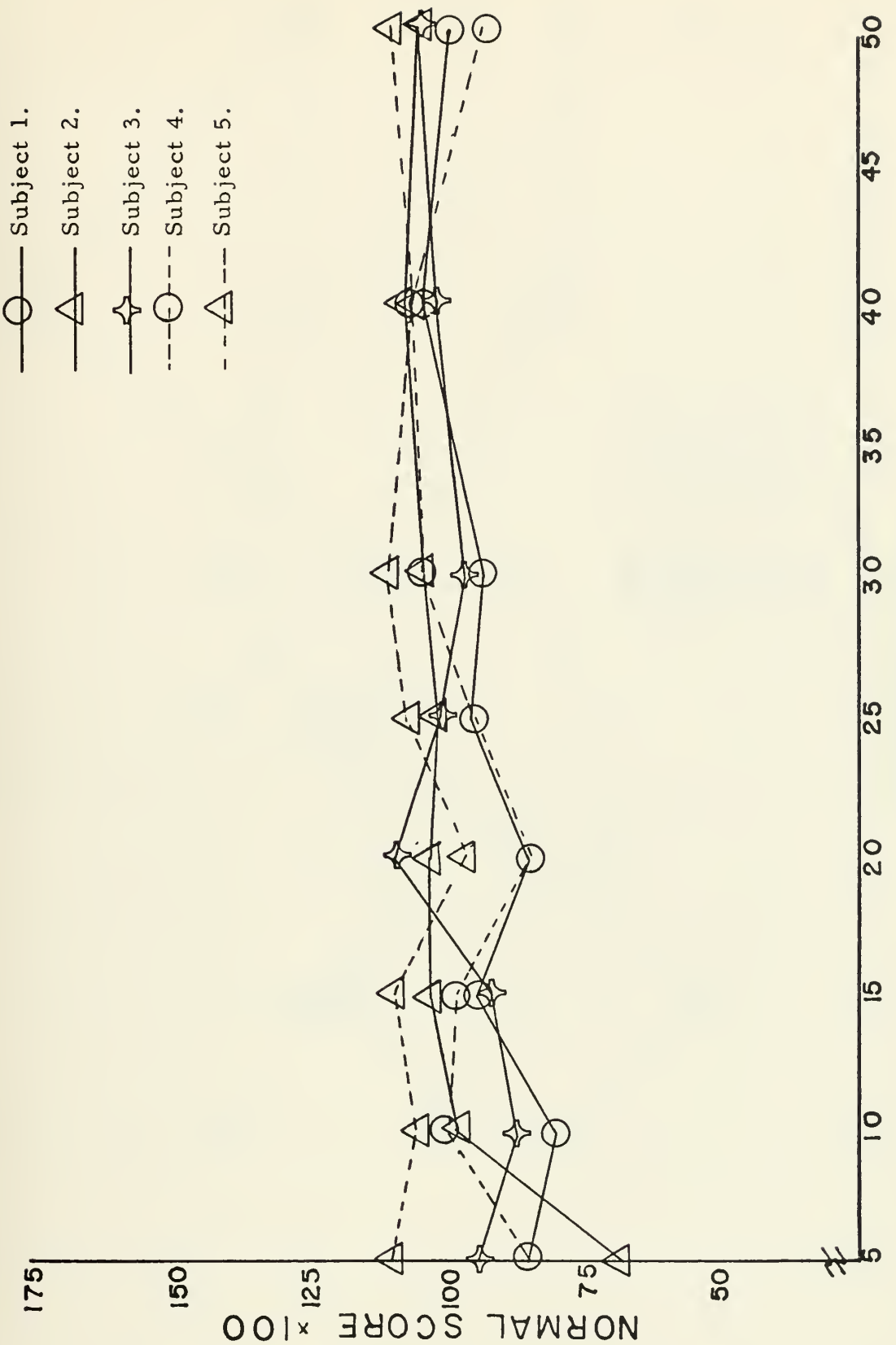


FIGURE C-2. SETUP TWO - G-LEVEL ONE

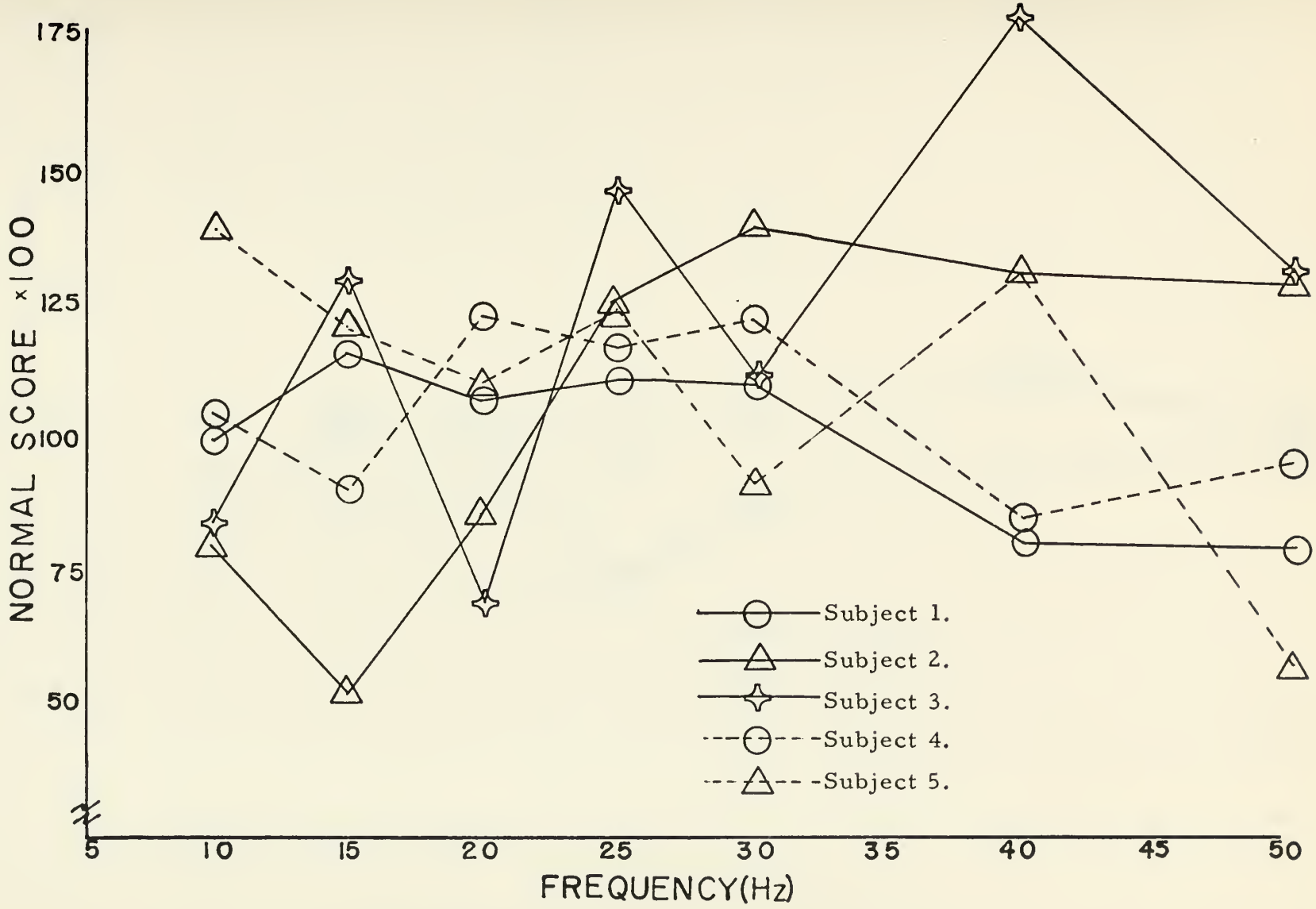


FIGURE C-3. SETUP ONE - G-LEVEL TWO

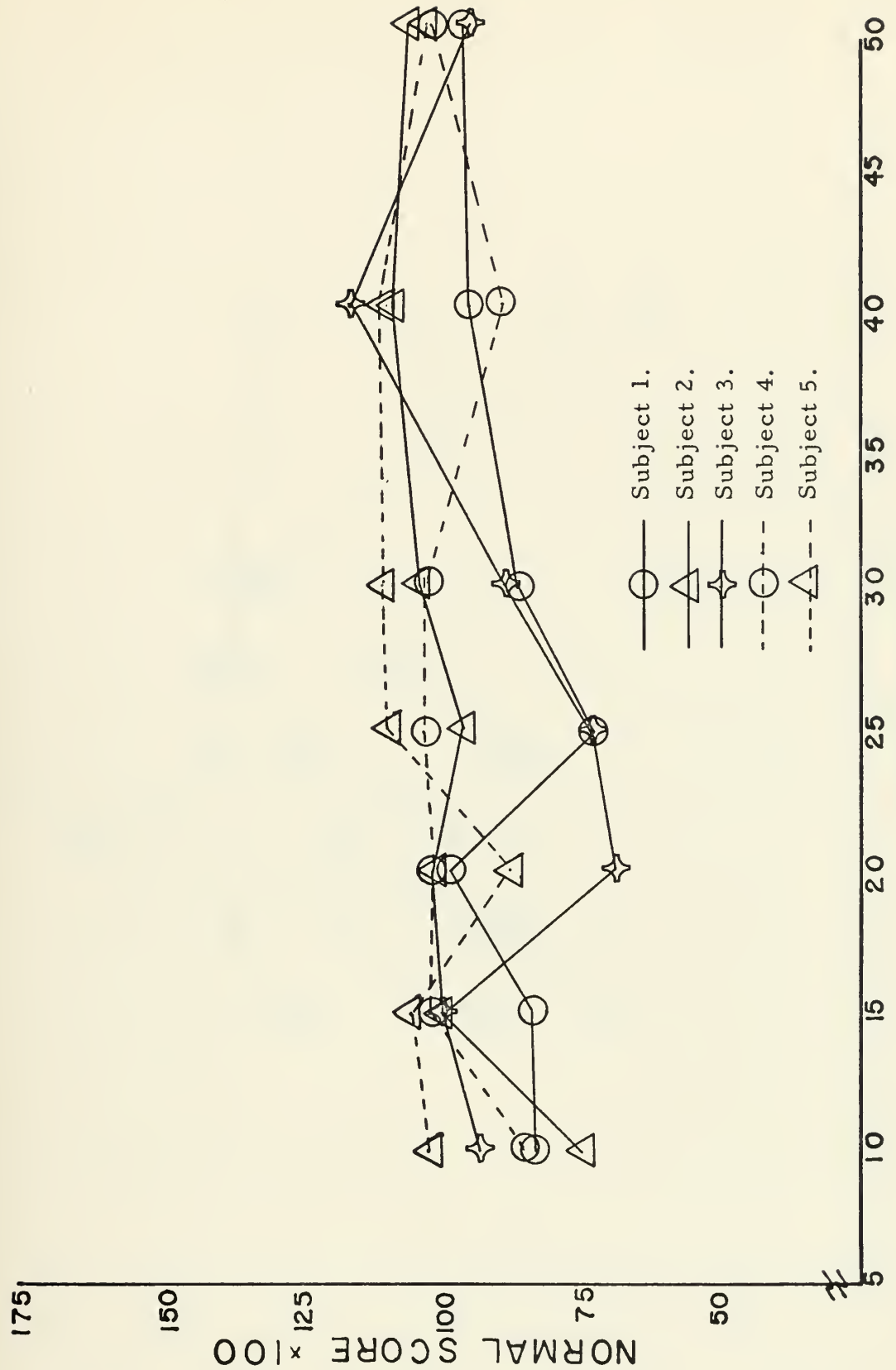


FIGURE C-4. SETUP TWO - G-LEVEL TWO

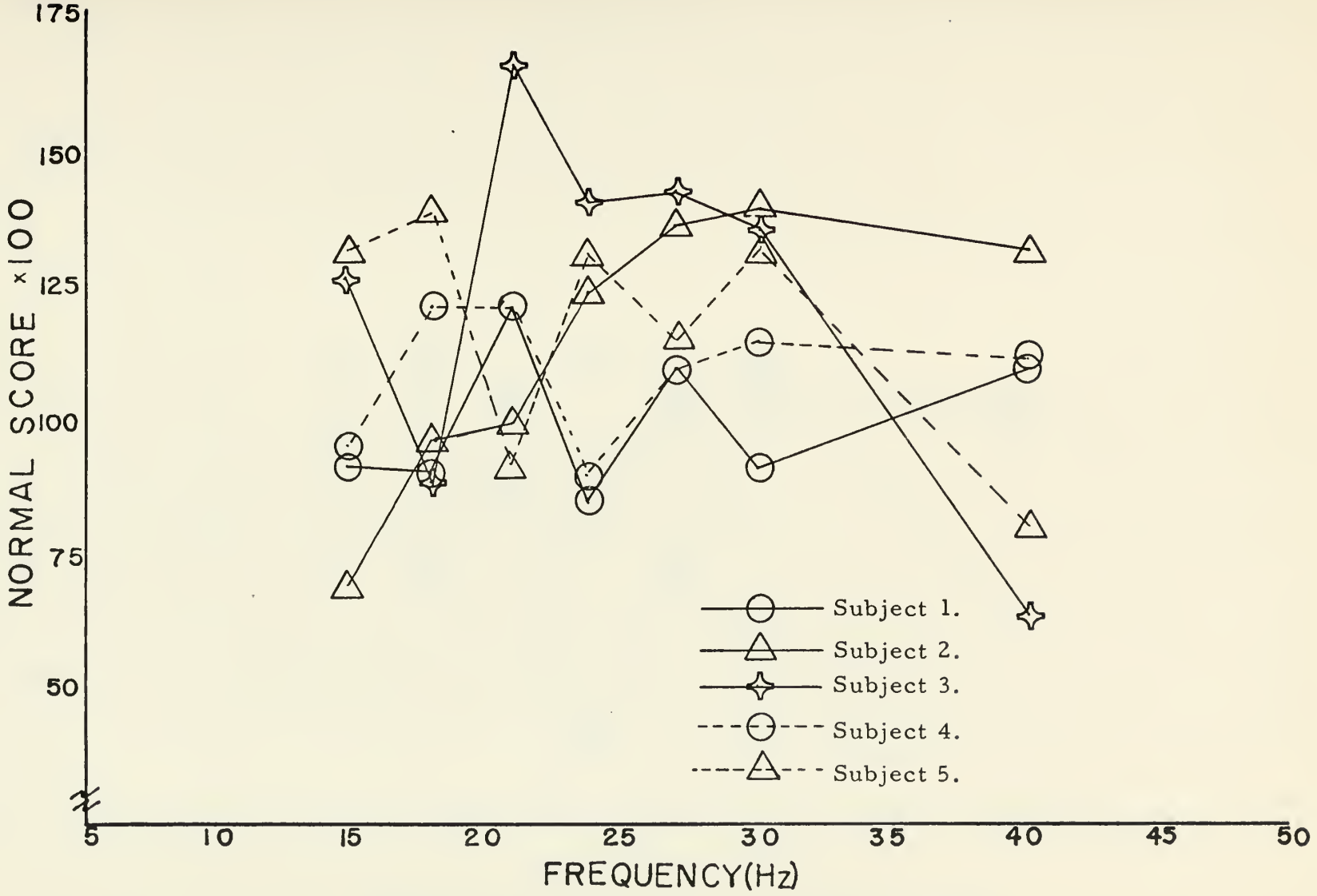


FIGURE C-5. SETUP ONE - G-LEVEL THREE

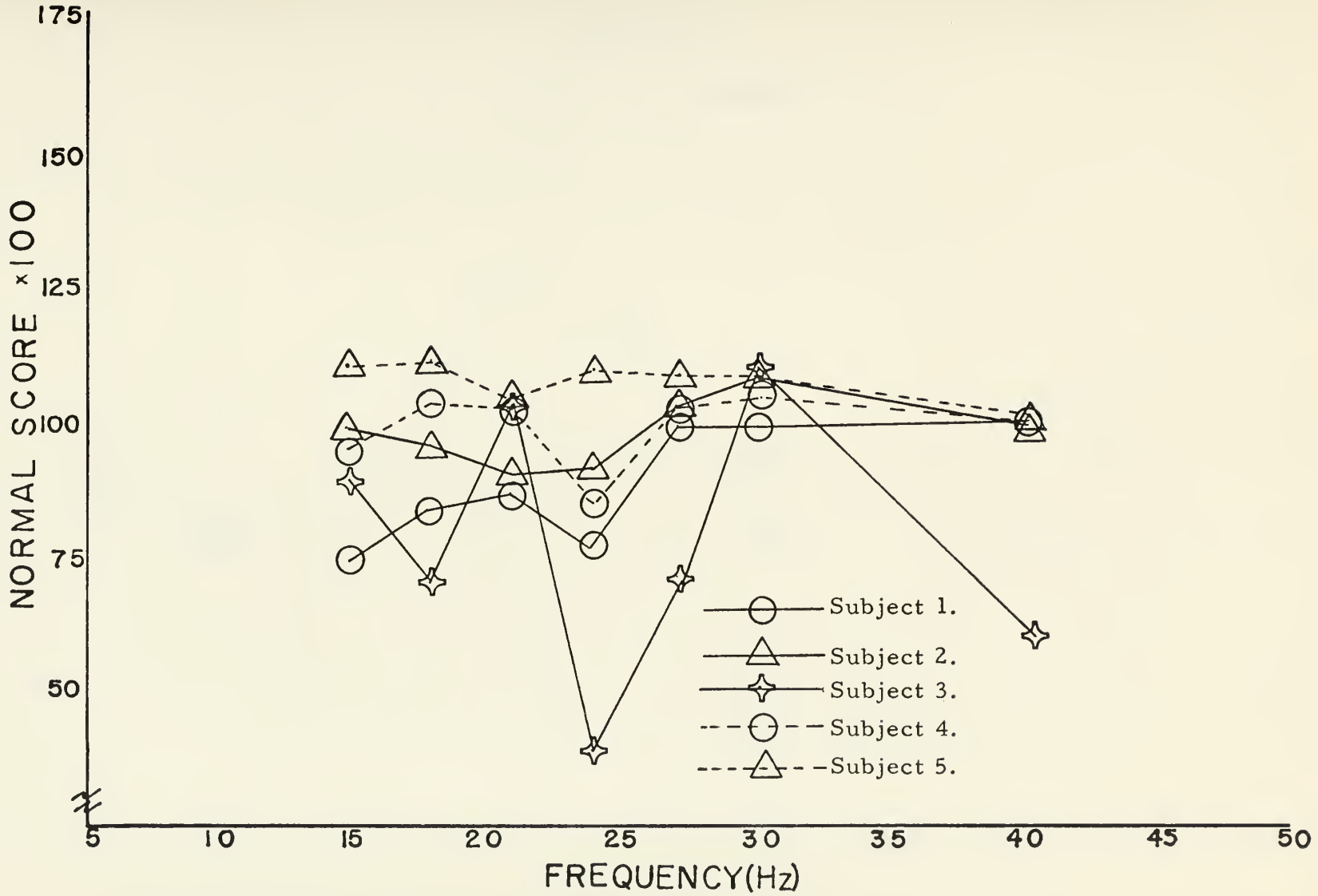
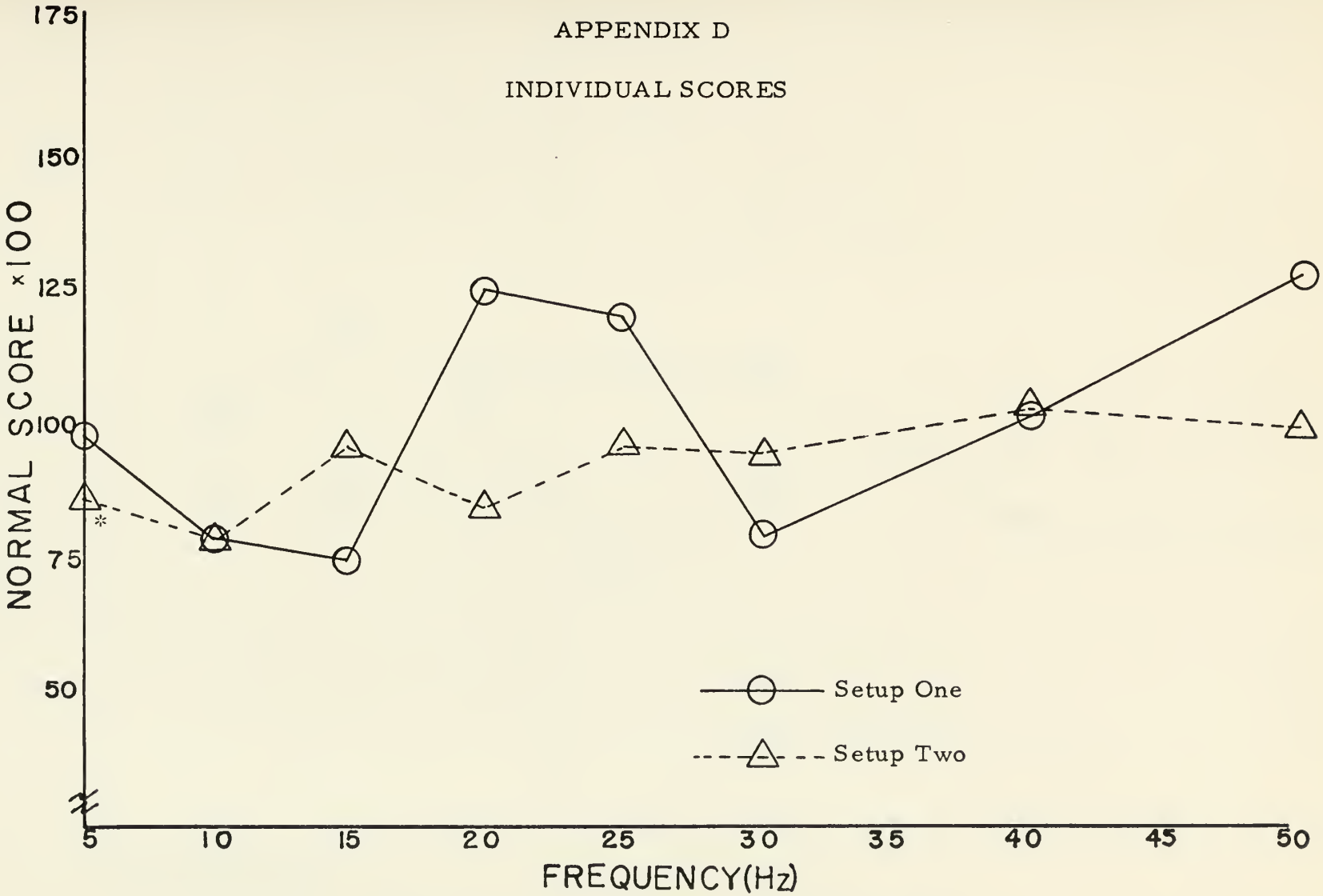


FIGURE C-6. SETUP TWO - G-LEVEL THREE

APPENDIX D

INDIVIDUAL SCORES



* "Uncomfortable"

FIGURE D-1. SUBJECT 1 G-LEVEL ONE

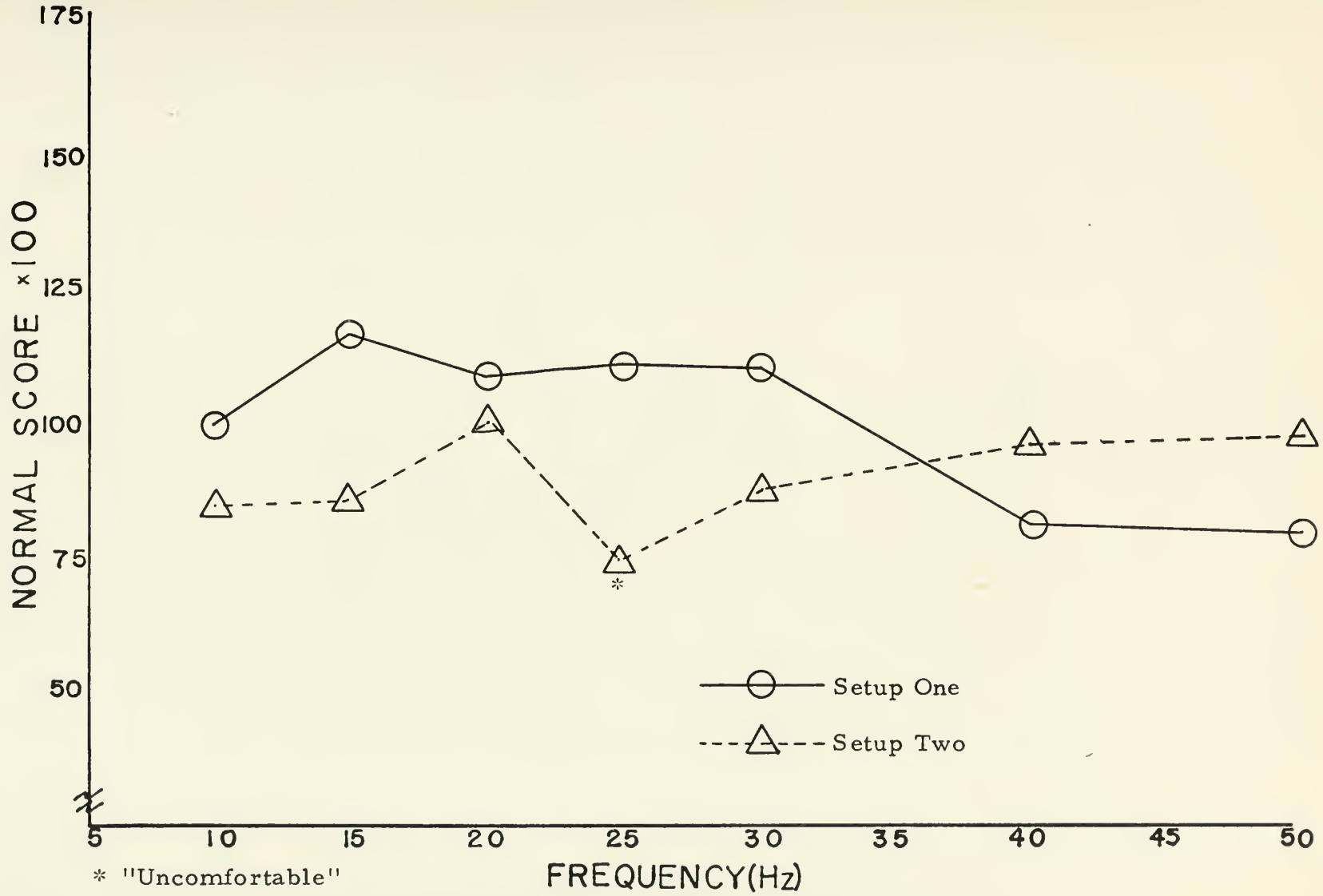


FIGURE D-2. SUBJECT 1 G-LEVEL TWO

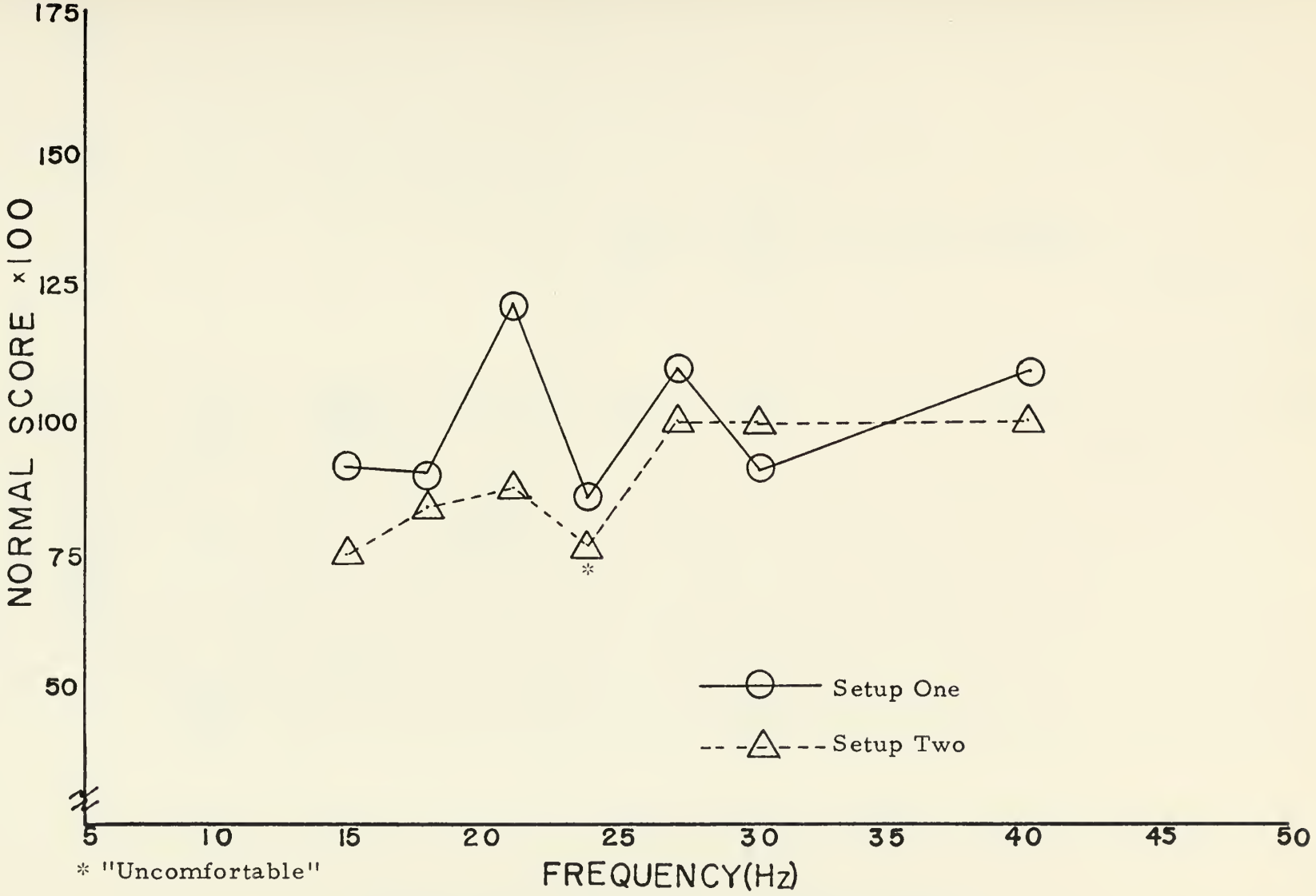


FIGURE D-3. SUBJECT 1 G-LEVEL THREE

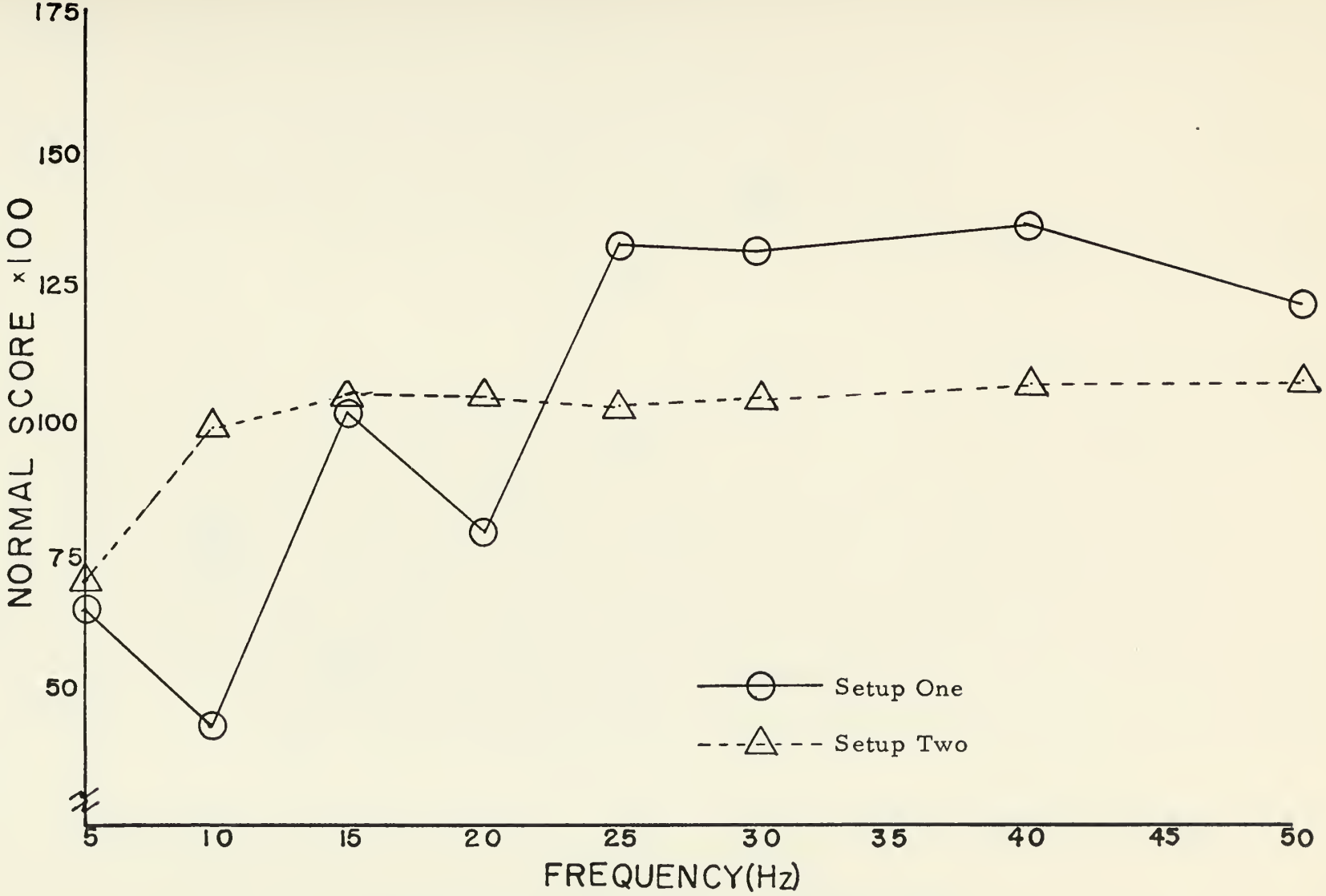


FIGURE D-4. SUBJECT 2 G-LEVEL ONE

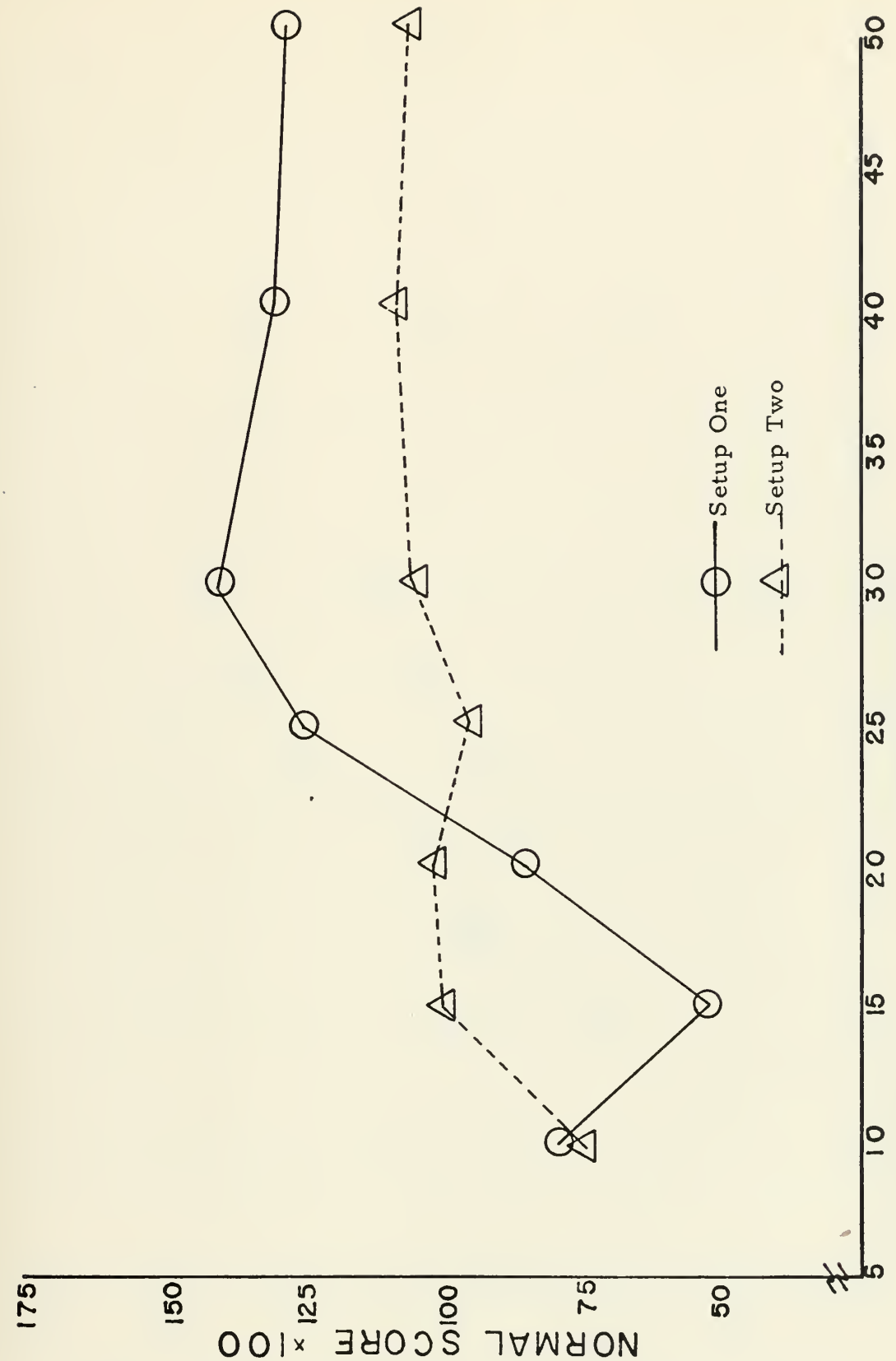
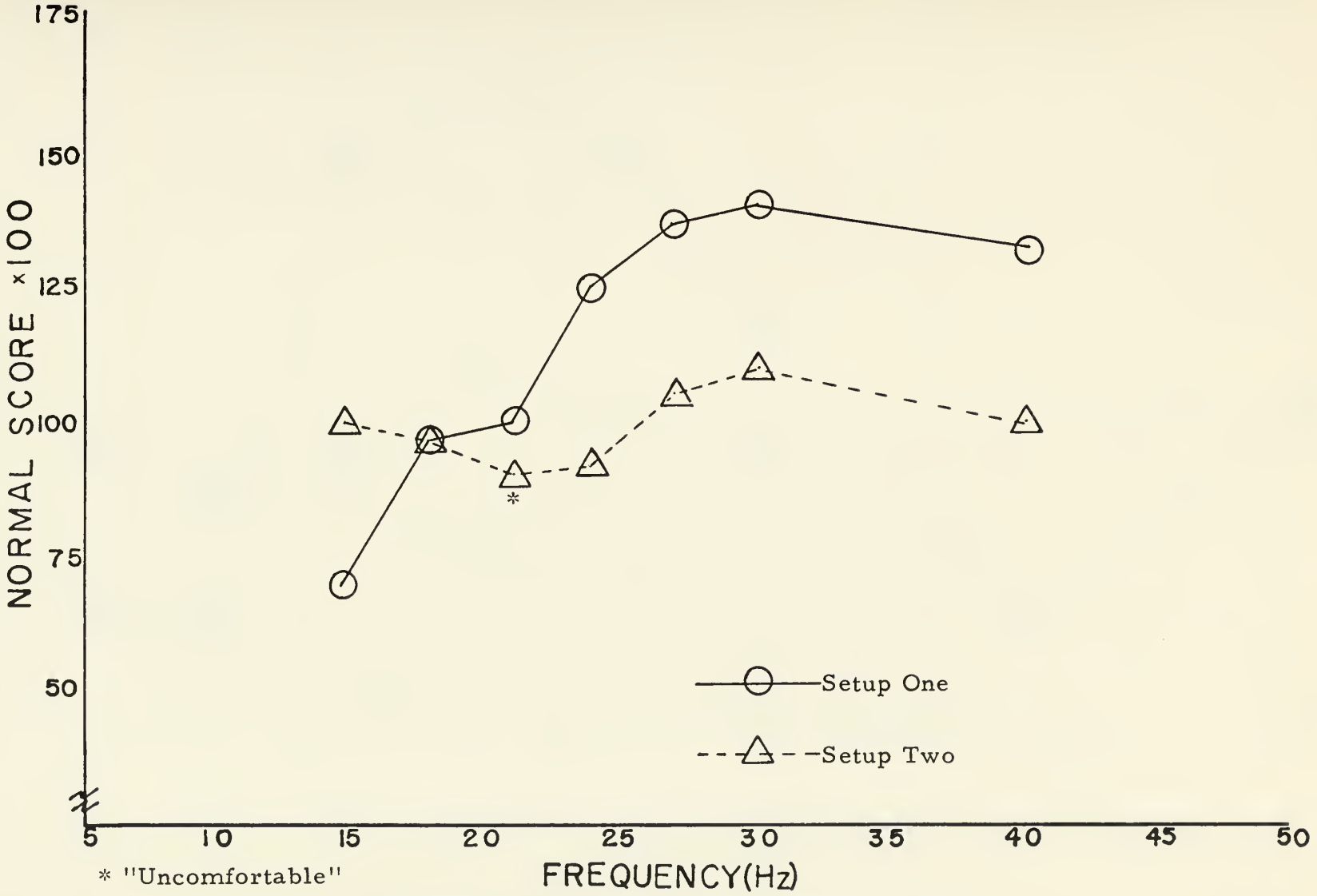


FIGURE D-5. SUBJECT 2 G-LEVEL TWO



* "Uncomfortable"

FIGURE D-6. SUBJECT 2 G-LEVEL THREE

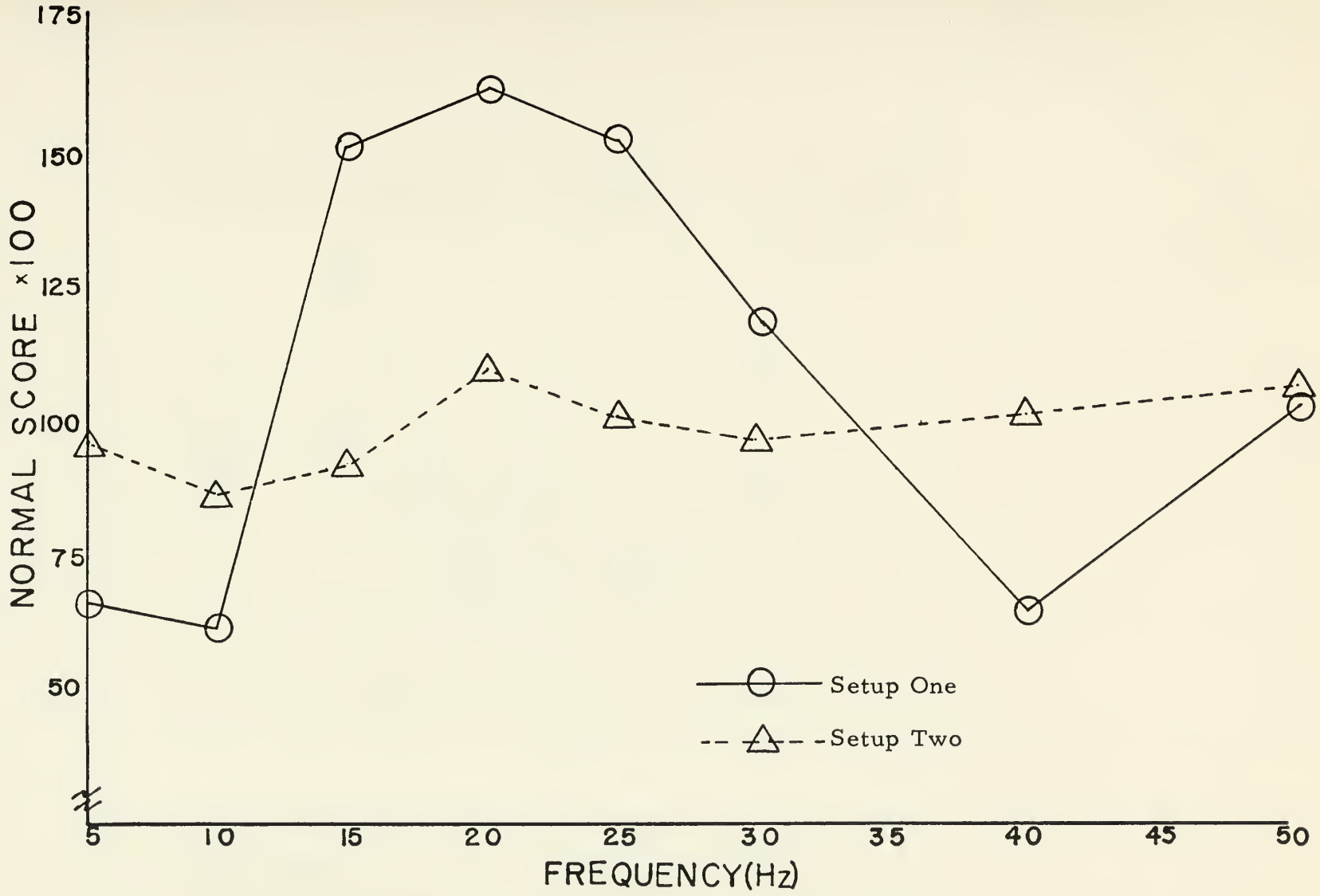


FIGURE D-7. SUBJECT 3 G-LEVEL ONE

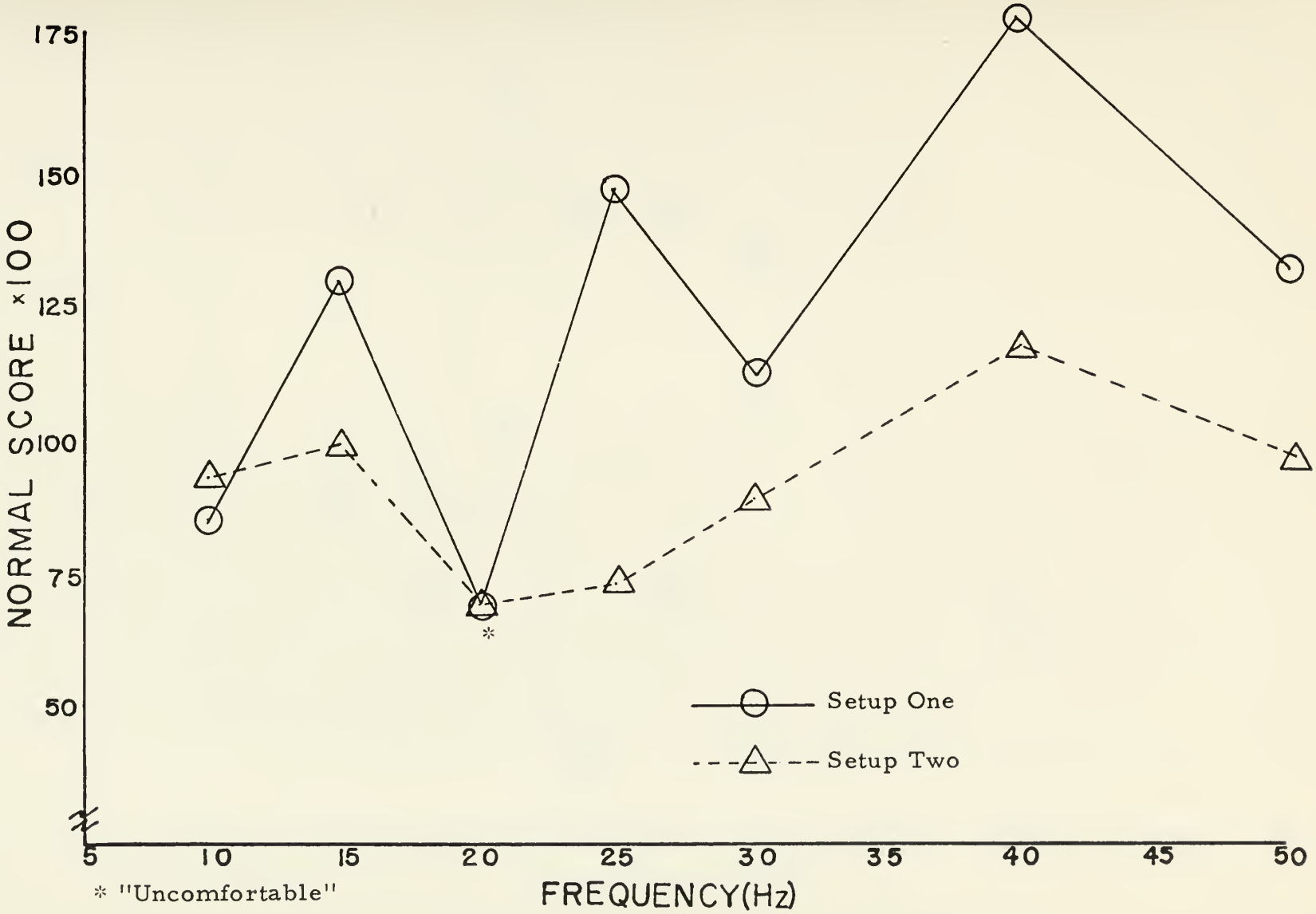


FIGURE D-8. SUBJECT 3 G-LEVEL TWO

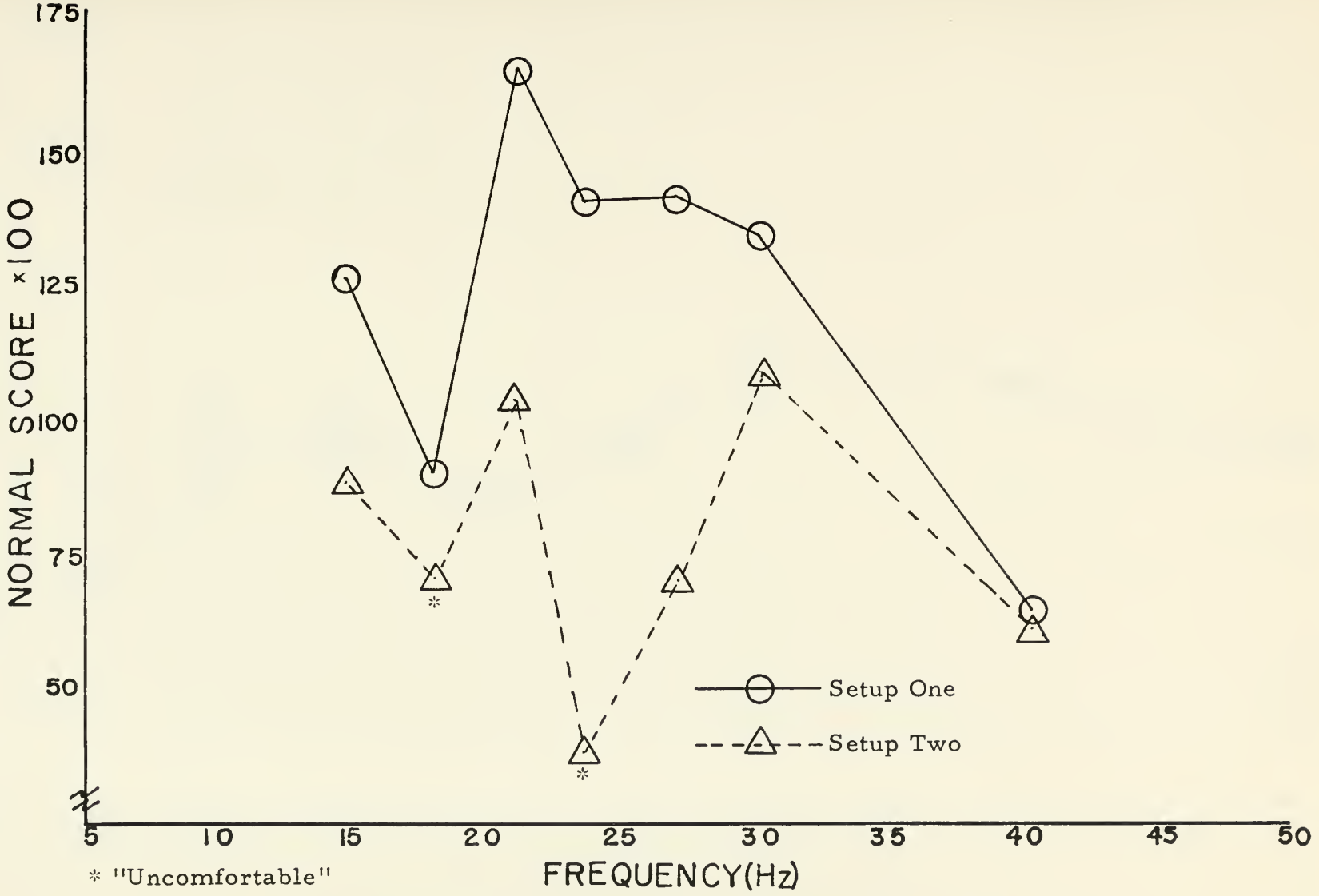


FIGURE D-9. SUBJECT 3 G-LEVEL THREE

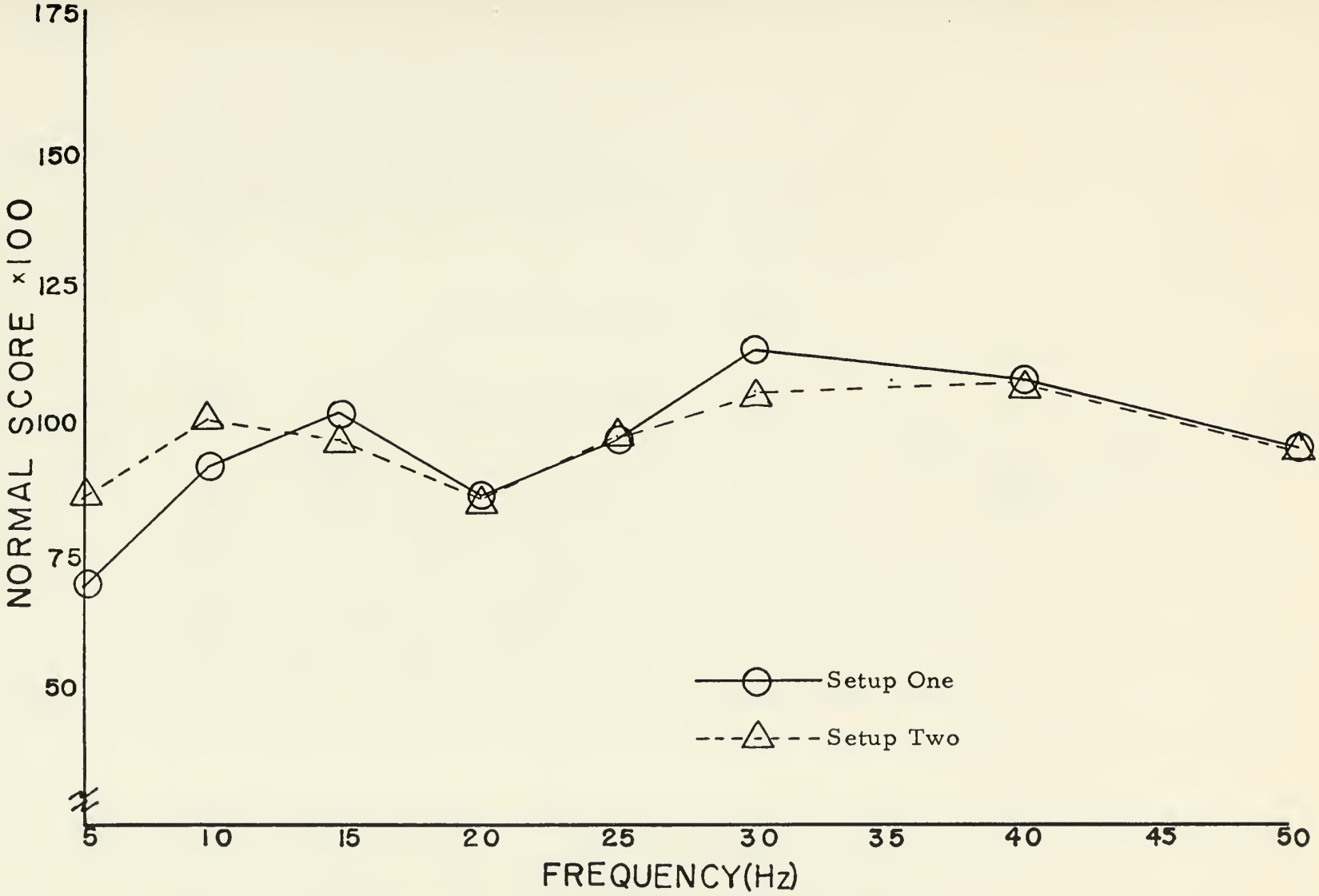


FIGURE D-10. SUBJECT 4 G-LEVEL ONE

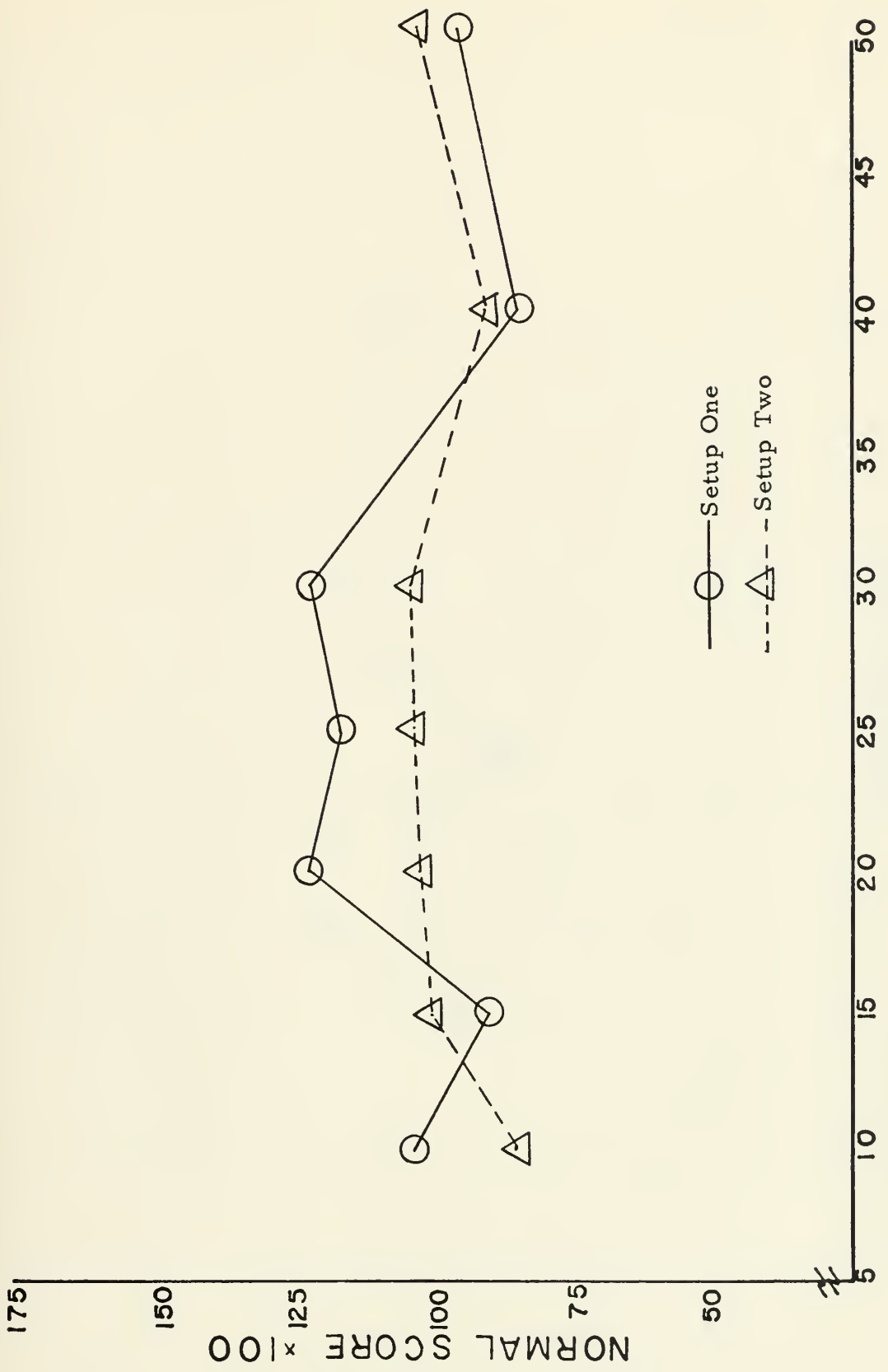


FIGURE D-11. SUBJECT 4 G-LEVEL TWO

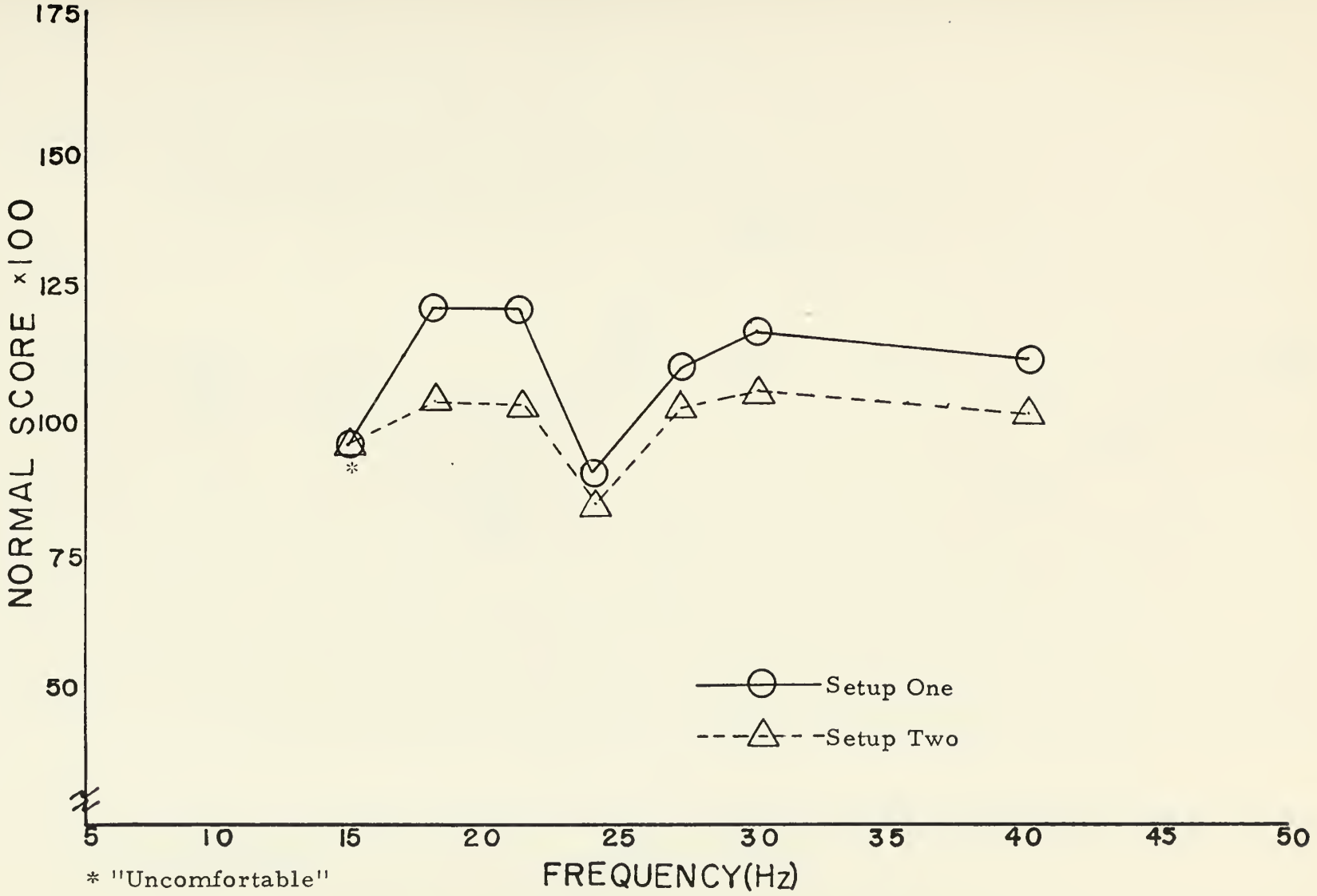


FIGURE D-12. SUBJECT 4 G-LEVEL THREE

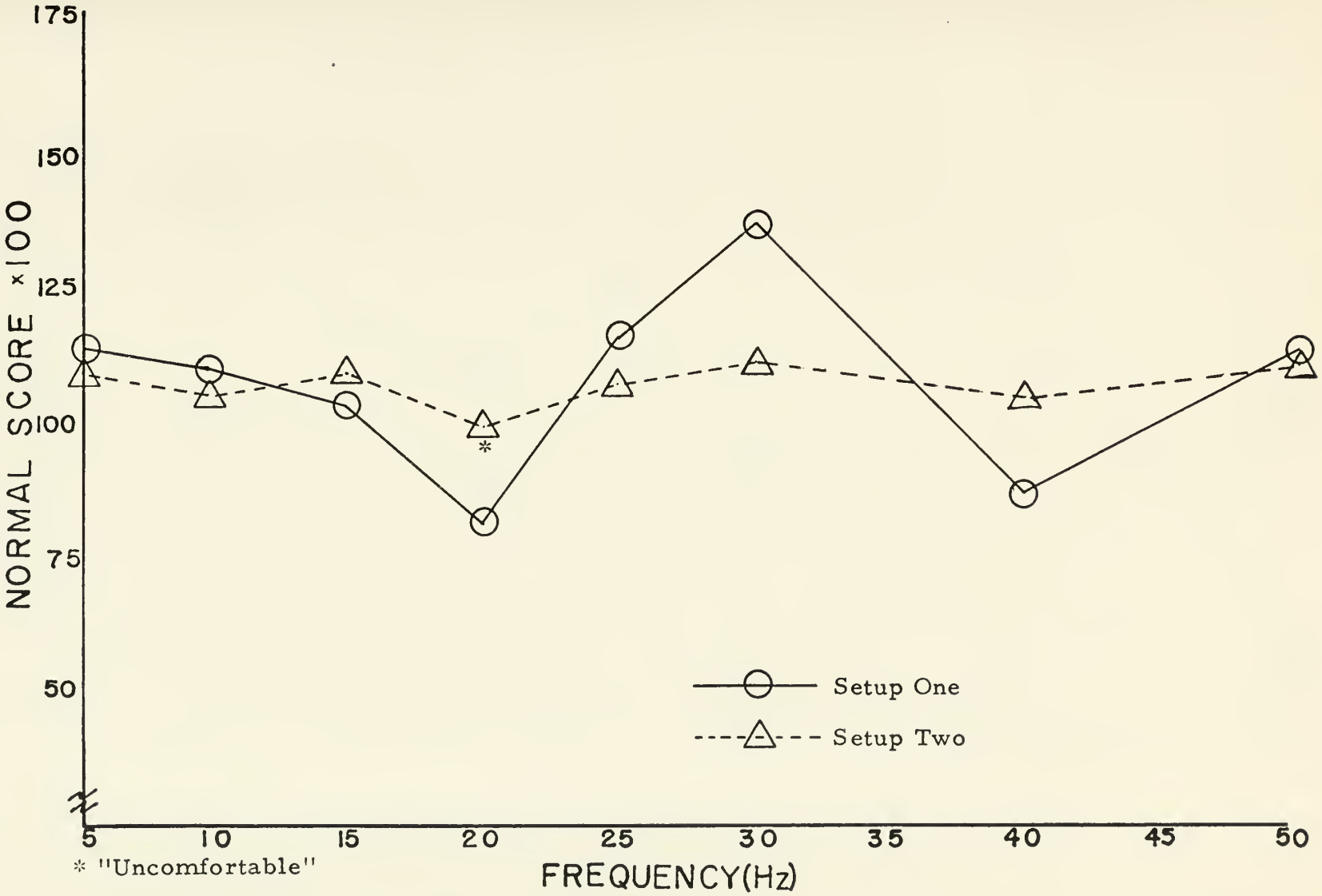


FIGURE D-13. SUBJECT 5 G-LEVEL ONE

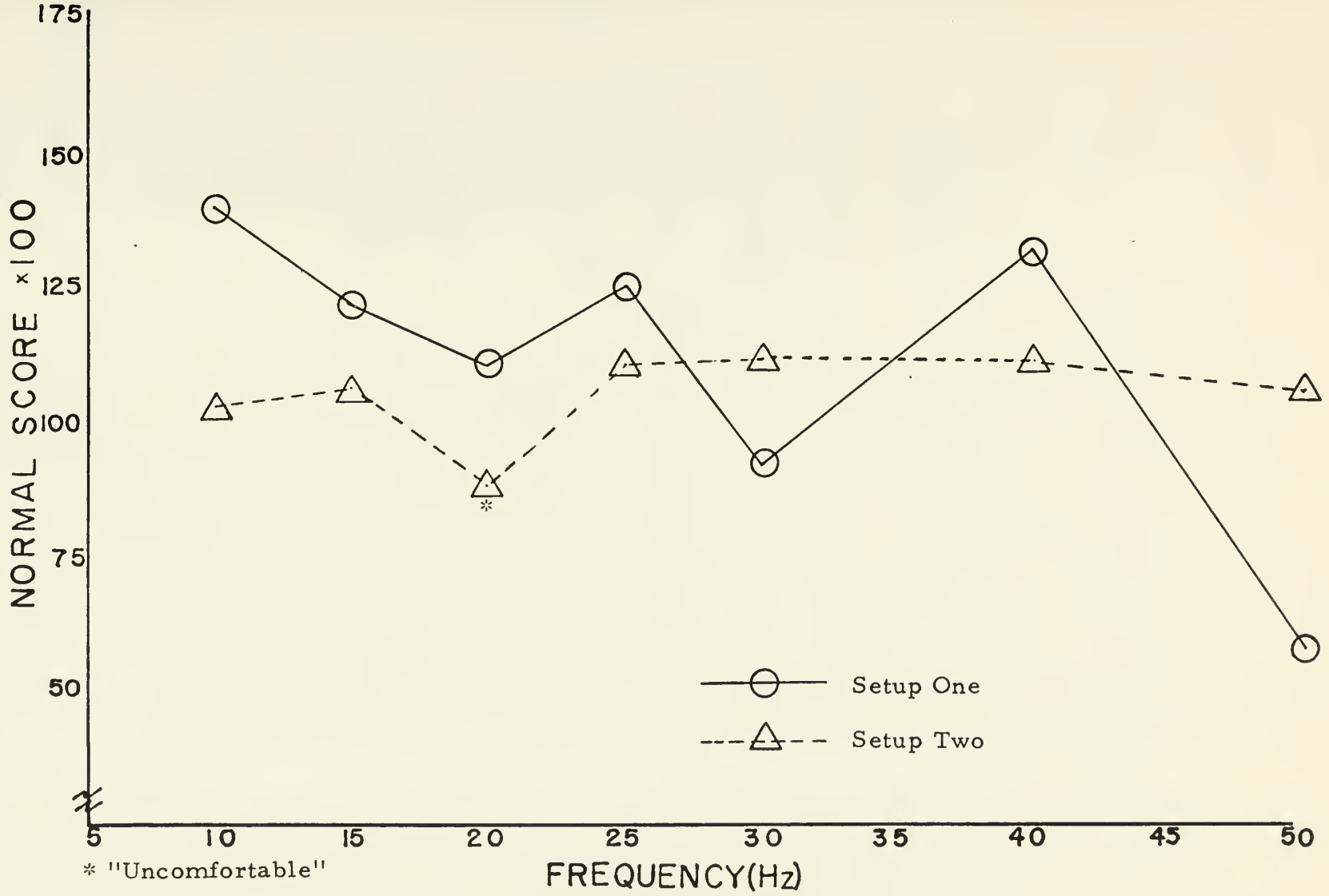


FIGURE D-14. SUBJECT 5 G-LEVEL TWO

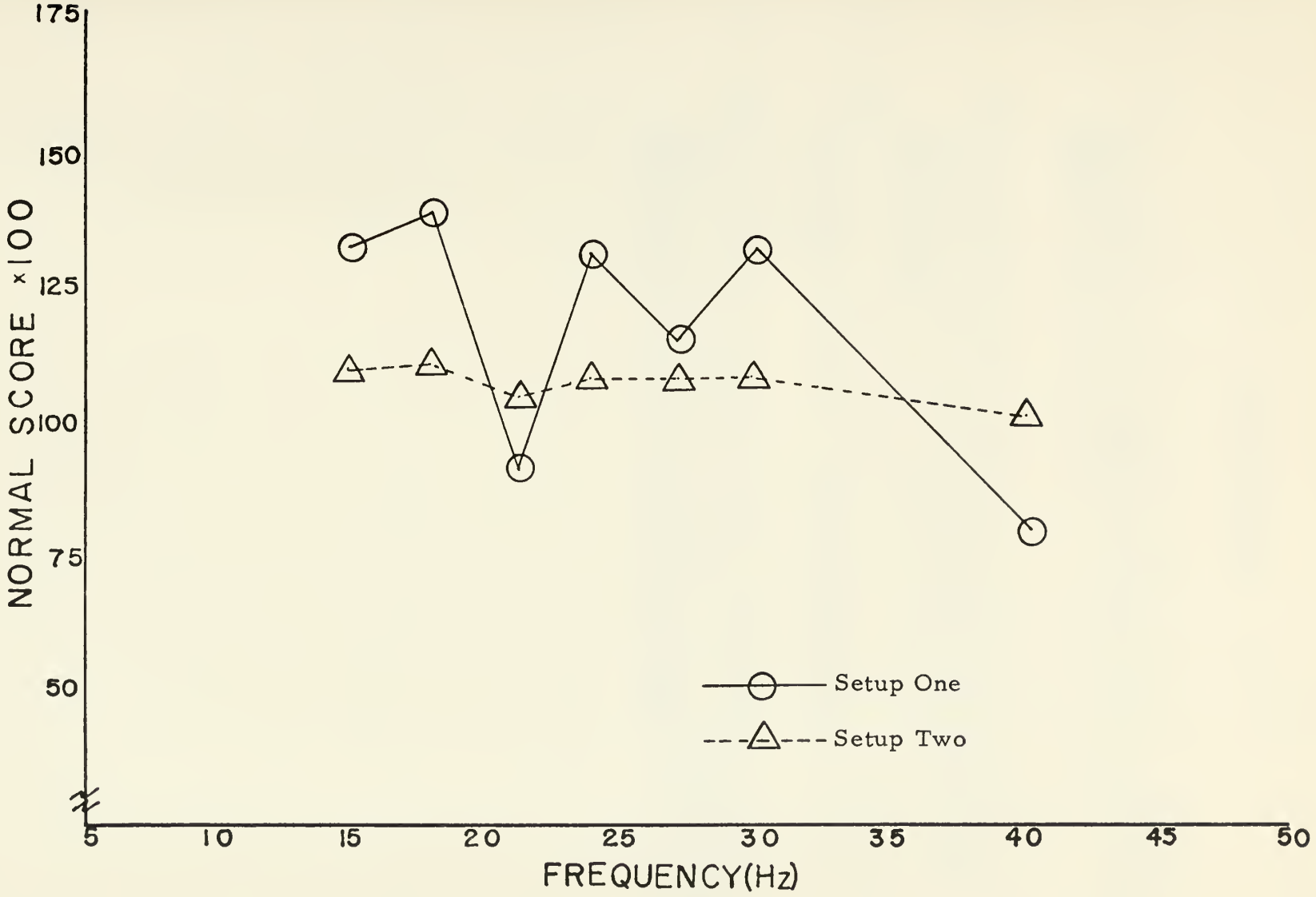


FIGURE D-15. SUBJECT 5 G-LEVEL THREE

REFERENCES

1. Naval Postgraduate School Report NPS-57LN70071A, A Simulator Evaluation of Pilot Performance and Acceptance of an Aircraft Rigid Cockpit Control System, by Donald M. Layton, 15 July 1970.

2. British Aircraft Corporation Limited, Guided Weapons Division, Report AD 854431L, Effects on Tracking Performance of Vibration in Each and in Combinations of the Heave, Sway and Roll Axes, by C. R. Shurmer, October 1967.

3. Woods, A. G., "Human Response to Low Frequency Sinusoidal and Random Vibration," Aircraft Engineering, p. 6-14, July 1967.

4. British Aircraft Corporation Limited, Guided Weapons Division, Human Factors Study Note Series 4, No. 7, A Review of the Effects of Low-Frequency Vibration on Man and His Tracking Performance, by C. R. Shurmer, June 1967.

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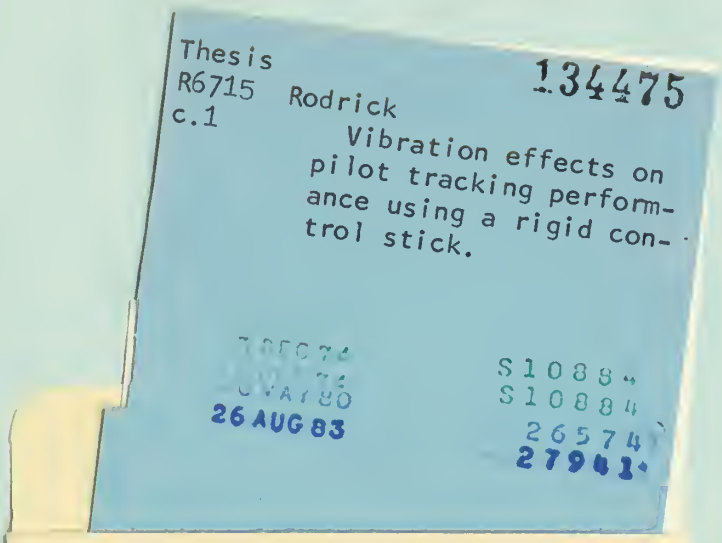
13. ABSTRACT

A simulator facility was built to study the effects of vibration on pilot tracking performance using a rigid control stick. Tests were conducted at frequencies from 5 to 50 hertz and accelerations up to 1.5 g's. Two vibration environments were studied: control stick only vibration and whole body vibration.

Twenty-two different frequency/g-level combinations were tested. The order of the runs was varied for each subject in an attempt to cancel out consistent learning effects. In general, performance scores for whole body vibration were lower than those for control stick only vibration although g-levels were less. All subjects experienced greater discomfort on the whole body vibration tests. All subjects showed a noticeable drop in performance on some runs in the 20-25 Hz frequency range. Additional study into vibration effects is warranted and comparisons should be made between effects using rigid and moveable control systems.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Rigid Control Stick						
Vibration Environment						
Body Damping						
Visual Acuity						
Pilot Comfort						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